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NASA CR 110148

SPECIMEN/CAPSULE PREPARATION USED ON THE JPL MATERIAL COMPATIBILITY PROGRAM

Final Report

April 1970

PSI
2017 camfield avenue
los angeles, cal. 90022
AREA CODE 213 OV5-4520
PRESSURE SYSTEMS, INC.

SPECIMEN/CAPSULE PREPARATION
USED ON THE JPL MATERIAL COMPATIBILITY PROGRAM

FINAL REPORT APRIL 1970

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PREPARED FOR
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

PSI REPORT NO. 525902-1
JPL P. O. NO. EB-525902

Submitted:

Dale W. Cox
Program Manager

Approved:

Donald H. Estes
President

PRESSURE SYSTEMS, INC.
2017 CAMFIELD AVENUE
LOS ANGELES, CALIFORNIA

FOREWARD

This report was prepared by PRESSURE SYSTEMS, INC., Los Angeles, California, and presents the technical procedures and results of the material compatibility program between August 7, 1967 and April 1970.

The work was performed under JPL Contract No. 952004 for the purpose of providing material specimens in hermetically sealed glass capsule/transducers filled with specified propellants for long term compatibility testing.

The program originated at the Jet Propulsion Laboratory under the technical direction of Mr. Louis R. Toth. The Cognizant Engineer on the program was Mr. Orville F. Keller.

The work was accomplished by Pressure Systems, Inc. at their Los Angeles Plant No. 1. Program Manager was Mr. Dale W. Cox.

ABSTRACT

The Jet Propulsion Laboratory's Long Term Materials Compatibility Test Program required preparing production quantities of hermetically sealed glass capsule/transducers. Each capsule was loaded with either one or two material specimens and filled with one of four different rocket engine propellants. Most capsule–transducers prepared for the program were delivered to JPL's Edwards Test Station for long term storage and monitoring.

In cooperation with JPL, Pressure Systems, Inc. developed "production line" procedures for:

1) Preparing material specimens in quantity and ensuring traceability and complete documentation of physical data on each specimen.
2) Conducting typical spacecraft production processes, such as welding, on certain specimen lots.
3) Preparing carefully annealed glass capsules with strain gages bonded to the exterior surface, resulting in a test capsule/transducer.
4) Carefully cleaning specimens and glass capsules in a Clean Room Trailer.
5) Loading the material specimen in the capsule/transducer.
6) Fusing a glass reducer section to the glass capsule neck.
7) Calibrating the capsule/transducer.
8) Filling the capsule/transducer with propellant.
9) Hermetically sealing the capsule/transducer.

Pressure Systems, Inc. delivered a grand total of 872 compatibility capsule/transducers, control capsules and test capsules under this contract. Problems, procedures and test methods are reported.

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CONTENTS (Cont'd)

ILLUSTRATIONS

1.0 INTRODUCTION AND SUMMARY

This report presents the results of preparing compatibility test capsules for the Jet Propulsion Laboratory (JPL) Long Term Compatibility Program during the period August 1967 to April 1970. The material specimens prepared by Pressure Systems, Inc. (PSI) covered a wide range of metals, as well as many polymers, used in spacecraft construction. The material specimens were loaded in glass capsules, filled with a propellant and hermetically sealed. Problems encountered in transferring laboratory procedures into a "production line" using, in so far as possible, standard commercial practices are discussed.

Metallic specimens were prepared in several forms, a basic "slug," welded specimens, brazed specimens and stressed specimens. Non-metallic specimens were fabricated as directed by the cognizant engineer.

Each glass capsule was filled with 20 cubic centimeters of propellant. Four types of propellants were used in the program:
(1) Hydrazine (N_2H_4); (2) Nitrogen Tetroxide (N_2O_4);
(3) Monomethylhydrazine (CH_3NHNH_3) ; and (4) Hydrazine - Hydrazine - Nitrate Mix (N_2H_4 - $N_2H_5NO_3$).

(Filling capsules with the last propellant was done only at JPL.)
Stringent safety precautions were observed at PSI in handling each propellant. At no time was more than one type of propellant allowed at the Pressure Systems' Plant.

Completed compatibility capsules (Appendix I) were frozen and normally delivered to JPL's Edwards Test Station by PSI truck. However, in some cases, capsules were delivered directly to JPL.

1.1 PROGRAM BACKGROUND

JPL foresaw the requirements for future very long range unmanned space missions on which the primary requirement would be high reliability of equipment after long periods of coasting through space. It was obviously necessary that all materials coming in contact with chemical propellants be "acceptably inert" for the mission duration. Consequently, a compatibility testing program was initiated to last several years.

Very little technical data on material compatibility in a vacuum over periods as great as years was available. Knowing the physical effects of chemical propellants on materials used in spacecraft construction is obviously highly important in designing reliable spacecraft. Consequently, JPL developed in house the technical methods and test procedure of obtaining such data with laboratory samples. General Specifications detailing these procedures were written (refer to list of applicable documents, paragraph 2.0). Subsequently, Pressure Sytems, Inc. was awarded a contract to:

Provide, except as otherwise stated herein, all necessary personnel and services, facilities and equipment, materials and supplies and utitities to prepare compatibility test samples. . .

The contract was awarded to PSI on August 7, 1967. PSI immediately commenced preparing a Clean Room Trailer to meet program requirements (class 100 certification). Simultaneously, the following documentation required by the contract was prepared for JPL approval:

(1) A detailed flow diagram;
(2) A full description of the specific facilities;
(3) A detailed schedule, and
(4) A Quality Assurance Plan.

Following approval by JPL of the documentation package, specimen production and capsule preparation commenced.

1.2 OBJECTIVES

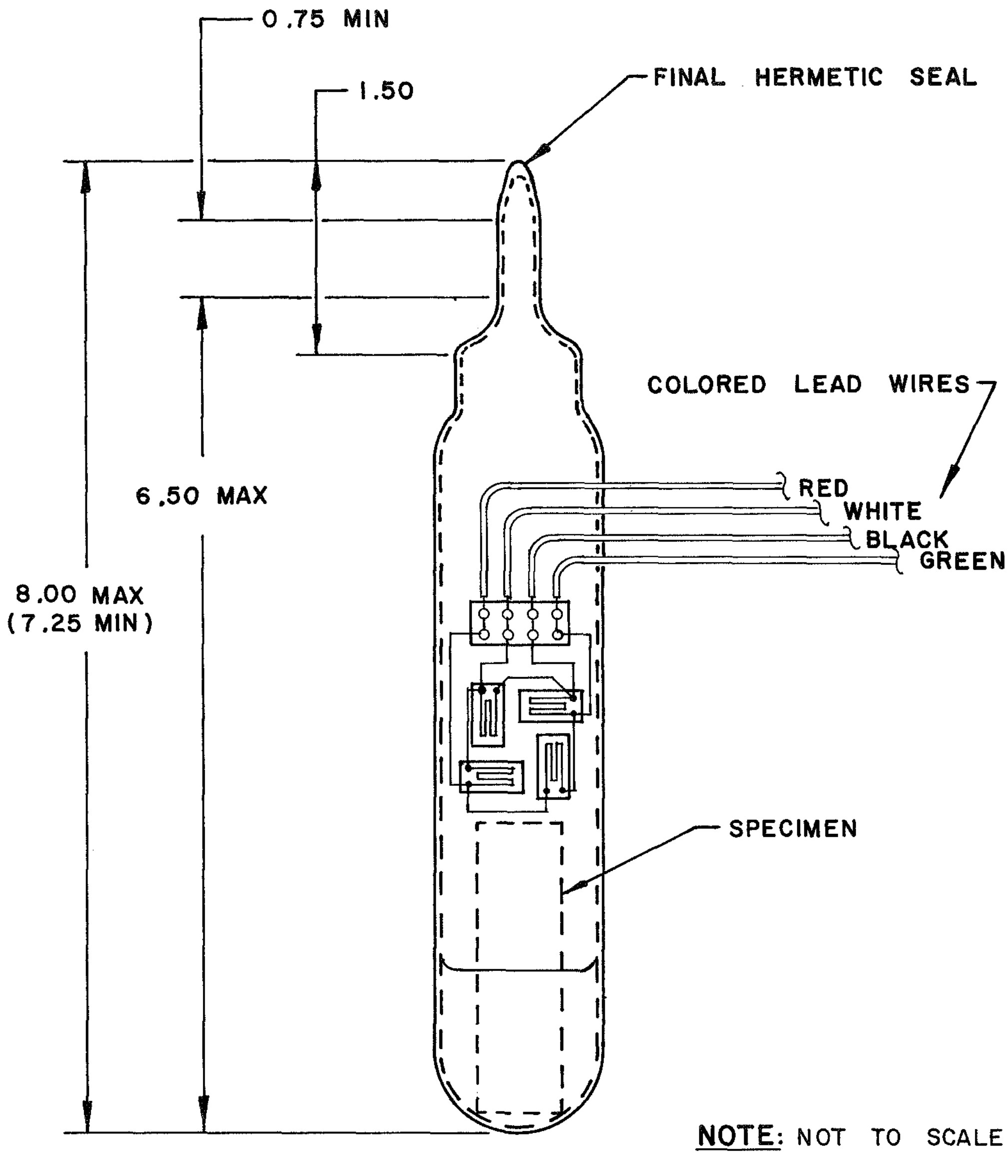
The specific program objectives were to prepare production quantities of compatibility capsules (see Figure 1). All capsules met stringent JPL Quality Assurance criteria as detailed below. Accomplishing this objective required developing production methods for relatively high volume production of small material specimens. Each metallic sample was required to have documentation giving material certification, alloy designation, specification number, producer, chemical composition, heat number, metallurgical state and processing history. Non-metallic specimens had similar information as available. During the fabrication cycle (in PSI's plant and at outside vendors) detailed Quality Control documentation was maintained. The production steps and flow sequence for preparing the metallic specimens are shown in Figure 2. Non-metallic specimens had a similar flow sequence.

1.3 SPECIFIC TASKS

Each metallic specimen was fabricated to specified dimensions and tolerances. Each basic metallic slug was approximately 3.00 inches long, .55 inches in width and .030 inches in thickness. Fabrication of the metallic slugs was made to the print requirements of PSI drawing SK 360 (Figure 3).

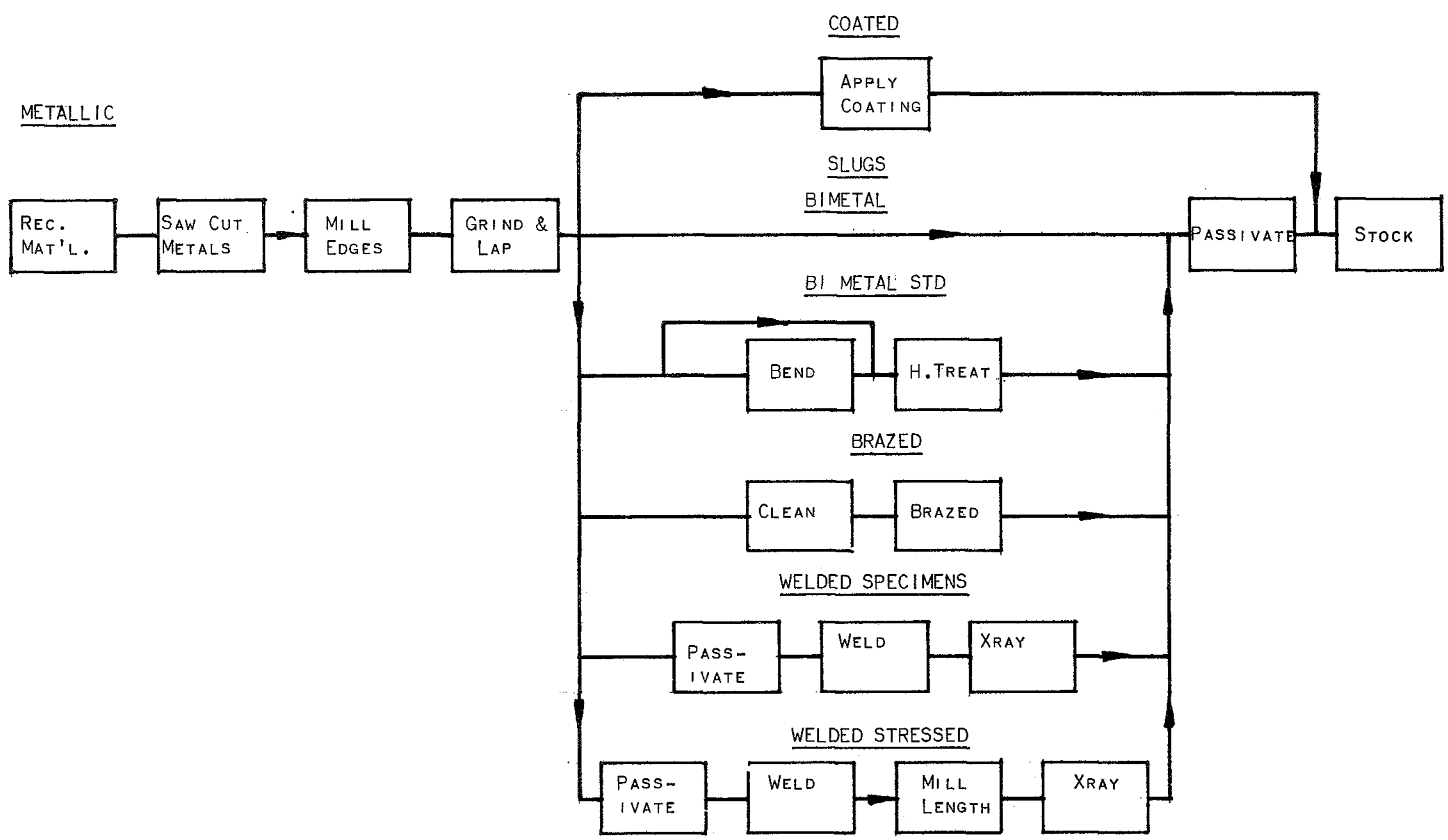
Coated metallic specimens were manufactured to the print requirements of PSI drawing SK 361 (Figure 4).

Bi-metallic specimens (Basic) were manufactured to the print requirements of PSI drawing SK 362 (Figure 5) and bi-metallic specimens (Bent) were manufactured to the print requirements of PSI drawing SK 363 (Figure 6).



COMPATIBILITY TEST CAPSULE (SEALED)

FIGURE 1



NOTE:
BIMETAL, WELDED, AND BRAZED SPECIMENS WILL TAKE TWO (2) SPECIMENS FOR ONE (1) CAPSULE LOADING.

METALLIC SPECIMEN FLOW CHART
FIGURE 2

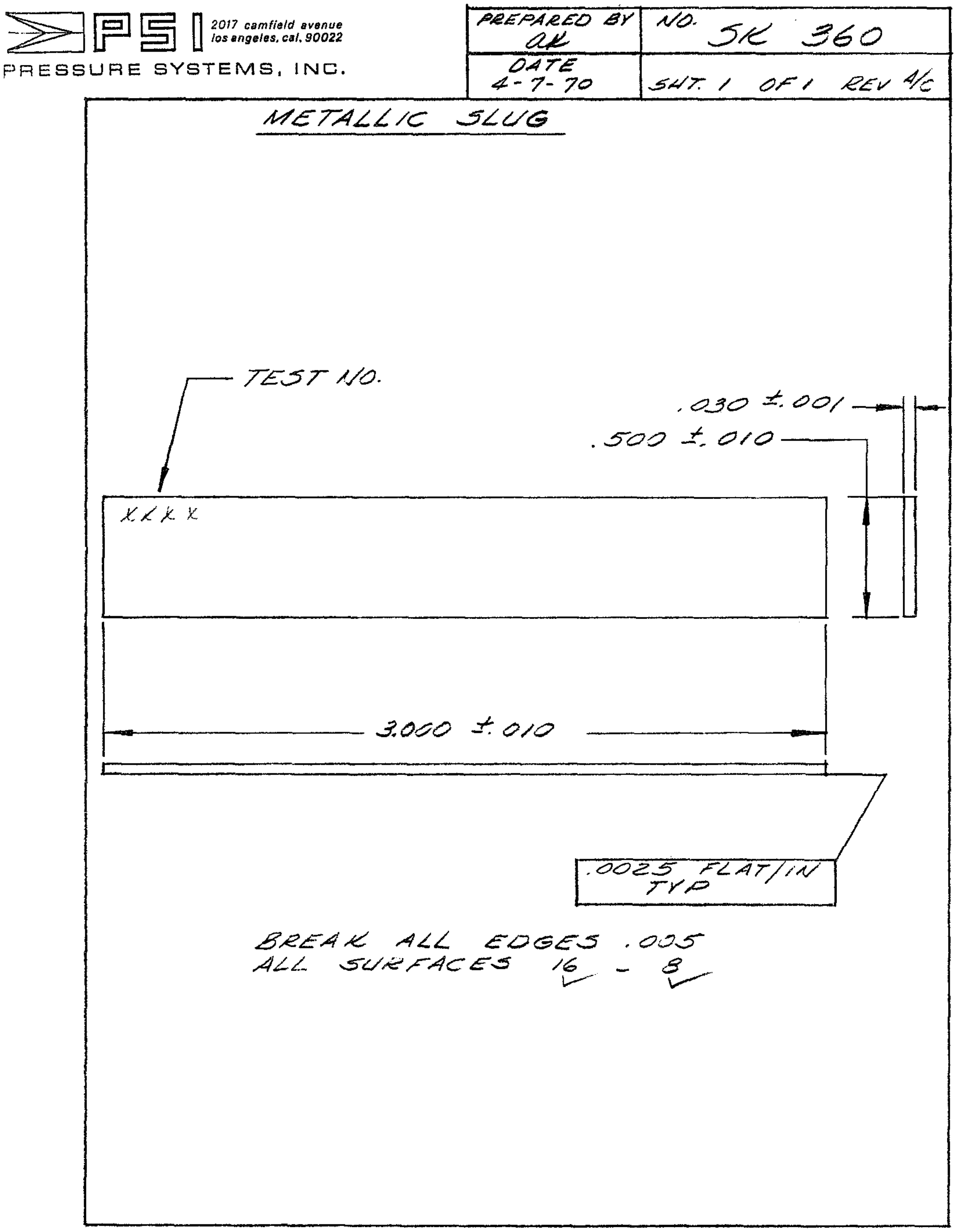

2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
DATE
4-7-70
NO. SK 360
SHT. 1 OF 1 REV A/C
METALLIC SLUG
TEST NO.
.030 ±.001
.500 ±.010
XXXX
3.000 ±.010
.0025 FLAT/IN
TYP
BREAK ALL EDGES .005
ALL SURFACES 16 - 8

Figure 3

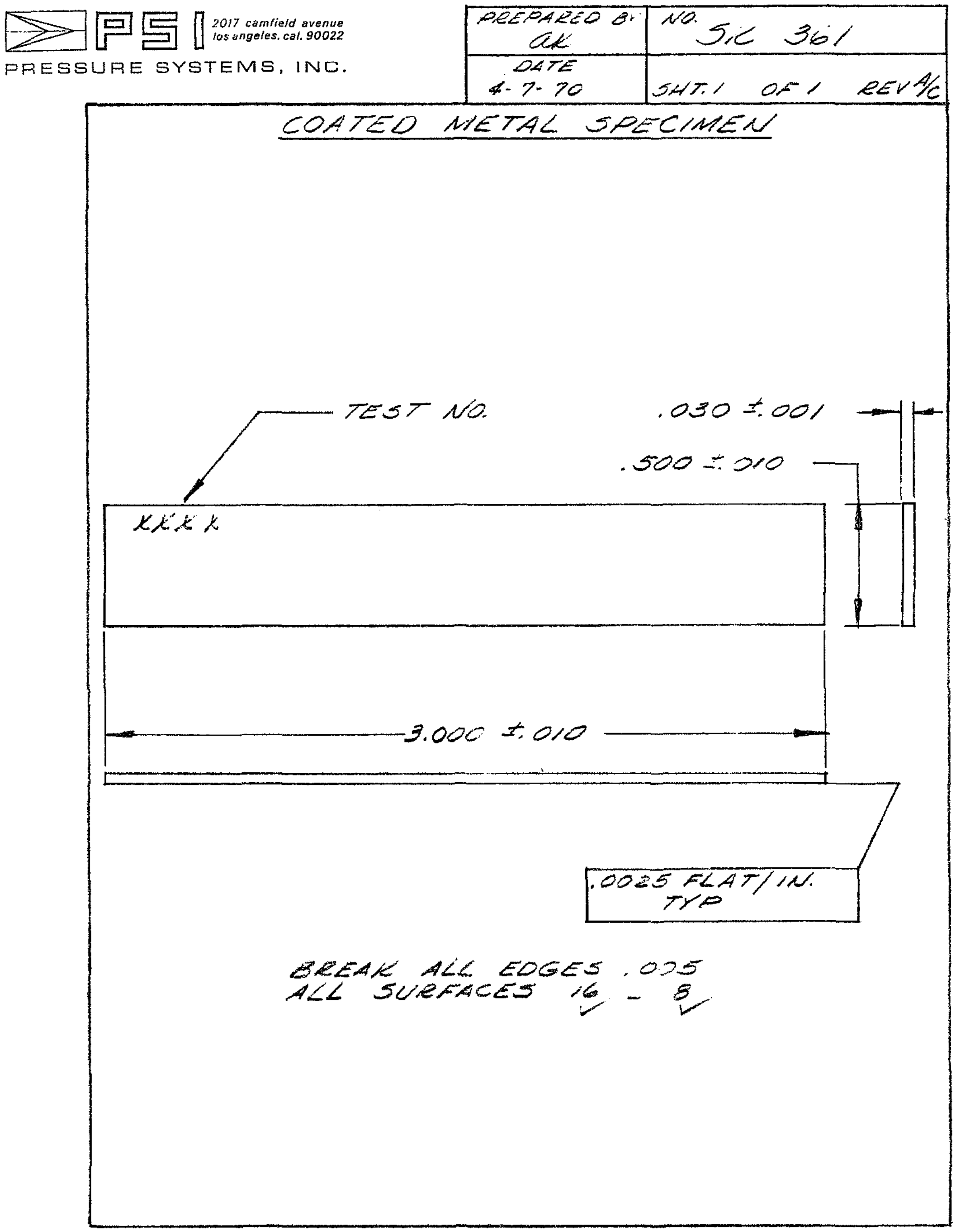

PSI
2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
AK
DATE
4-7-70
NO. SK 361
SHT. 1 OF 1 REV A/C
COATED METAL SPECIMEN
TEST NO.
.030 ±.001
.500 ±.010
XXXX
3.000 ±.010
.0025 FLAT/IN.
TYP
BREAK ALL EDGES .005
ALL SURFACES 16 - 8

Figure 4

2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.

PREPARED BY ak	NO. SK 362
DATE 4-7-70	SHT. 1 OF 1 REV A/C

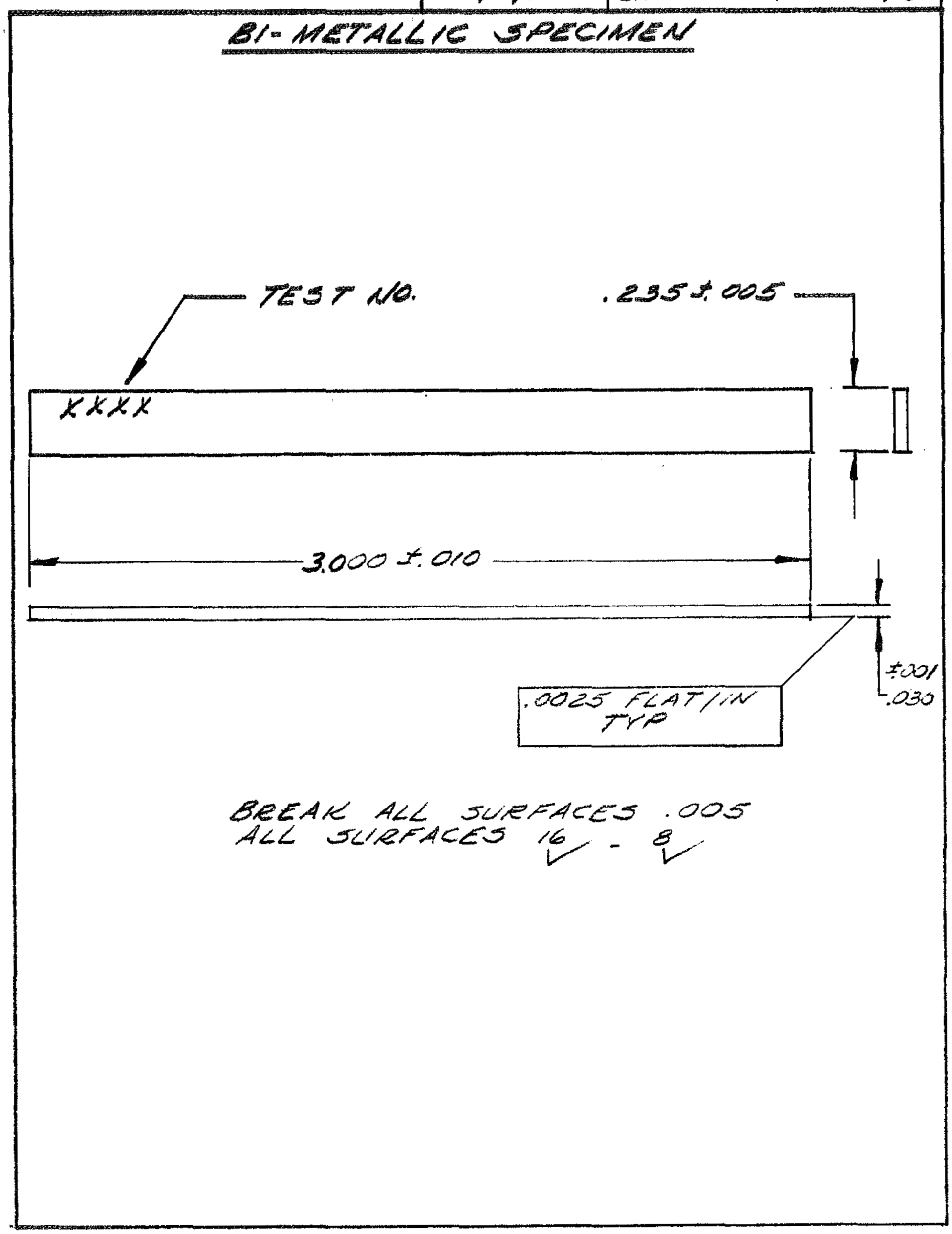


Figure 5

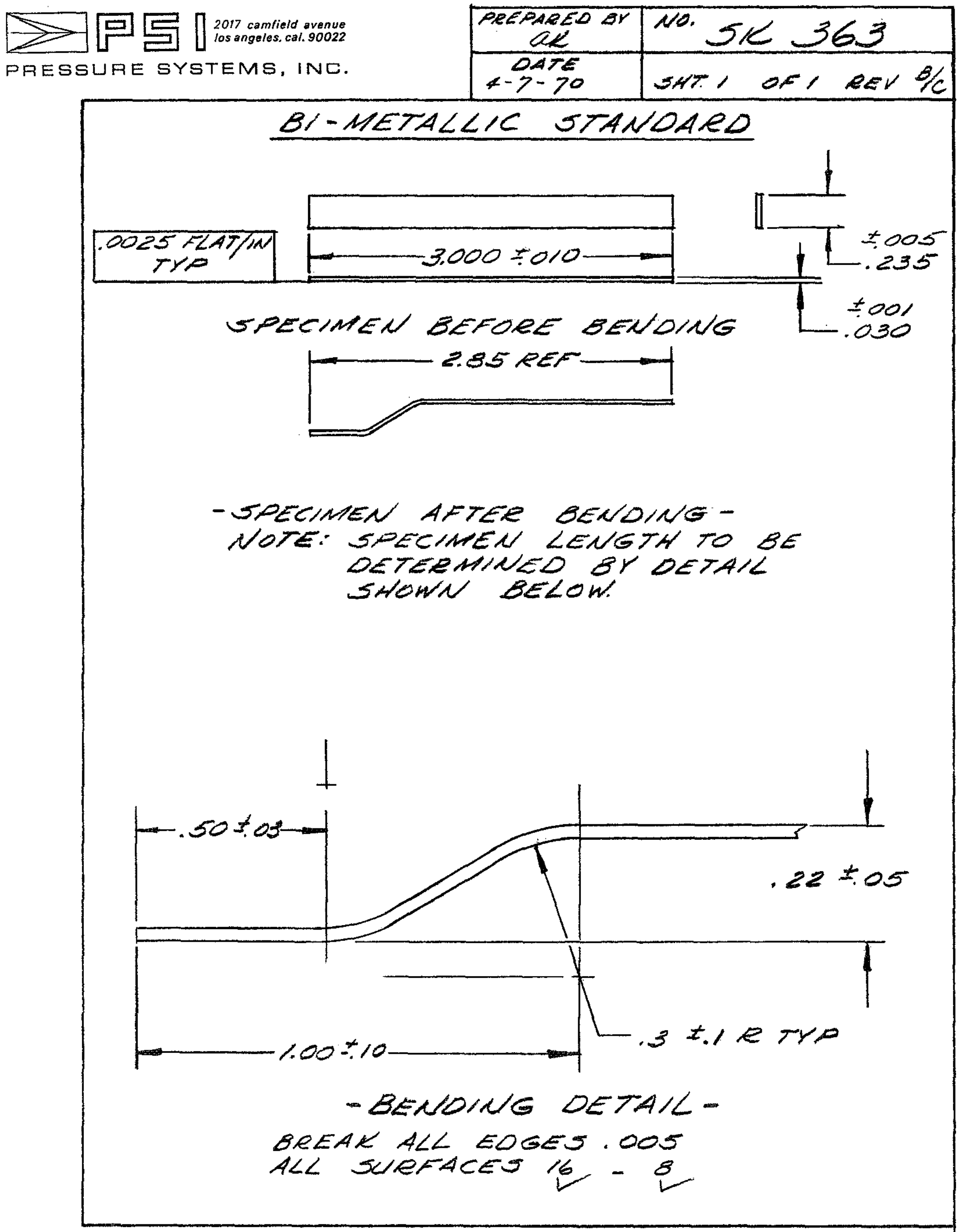

PSI
2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
DATE
4-7-70
NO. SK 363
SHT. 1 OF 1 REV B/C
BI-METALLIC STANDARD
.0025 FLAT/IN TYP
3.000 ±.010
±.005
.235
±.001
.030
SPECIMEN BEFORE BENDING
2.85 REF
-SPECIMEN AFTER BENDING-
NOTE: SPECIMEN LENGTH TO BE DETERMINED BY DETAIL SHOWN BELOW.
.50 ±.03
.22 ±.05
.3 ±.1 R TYP
1.00 ±.10
-BENDING DETAIL-
BREAK ALL EDGES .005
ALL SURFACES 16 - 8

Figure 6

Metallic stressed specimens were manufactured to the print requirements of PSI drawing SK 364 (Figure 7).

Metallic welded specimens were manufactured to the print requirements of PSI drawing SK 365 (Figure 8).

Metallic welded stressed specimens were manufactured to the print requirements of PSI drawing SK 366 (Figure 9).

Metallic bonded specimens (brazed) were manufactured to the print requirements of PSI drawing SK 367 (Figure 10).

Identification of each specimen was carefully controlled and met JPL General Specification requirements. Capsule/transducers were identified with two separate methods, in case one should be lost in handling.

Surface treatment, cleaning, passivating and handling procedures of specimens were accomplished to JPL General Specification requirements.

Glass capsules were furnished by JPL to the contract. PSI was required to anneal each capsule, pressure test one out of each 100 capsules, sand blast a specific area for attaching strain gages, clean the capsule in a detergent (Joy) solution, attach the strain gages, solder the bridge, alcohol proof the strain gages, calibrate the strain gage bridge output, and final clean the capsule in the clean room trailer.

Subsequently, the specimens were loaded in the glass capsules, glass reducers fused to the capsule neck, the capsules filled with 20cc of a propellant, the propellant frozen, a vacuum pulled on the capsule and the glass reducer neck fused shut to form a hermetic seal. Capsule/transducers were then ready for shipment.

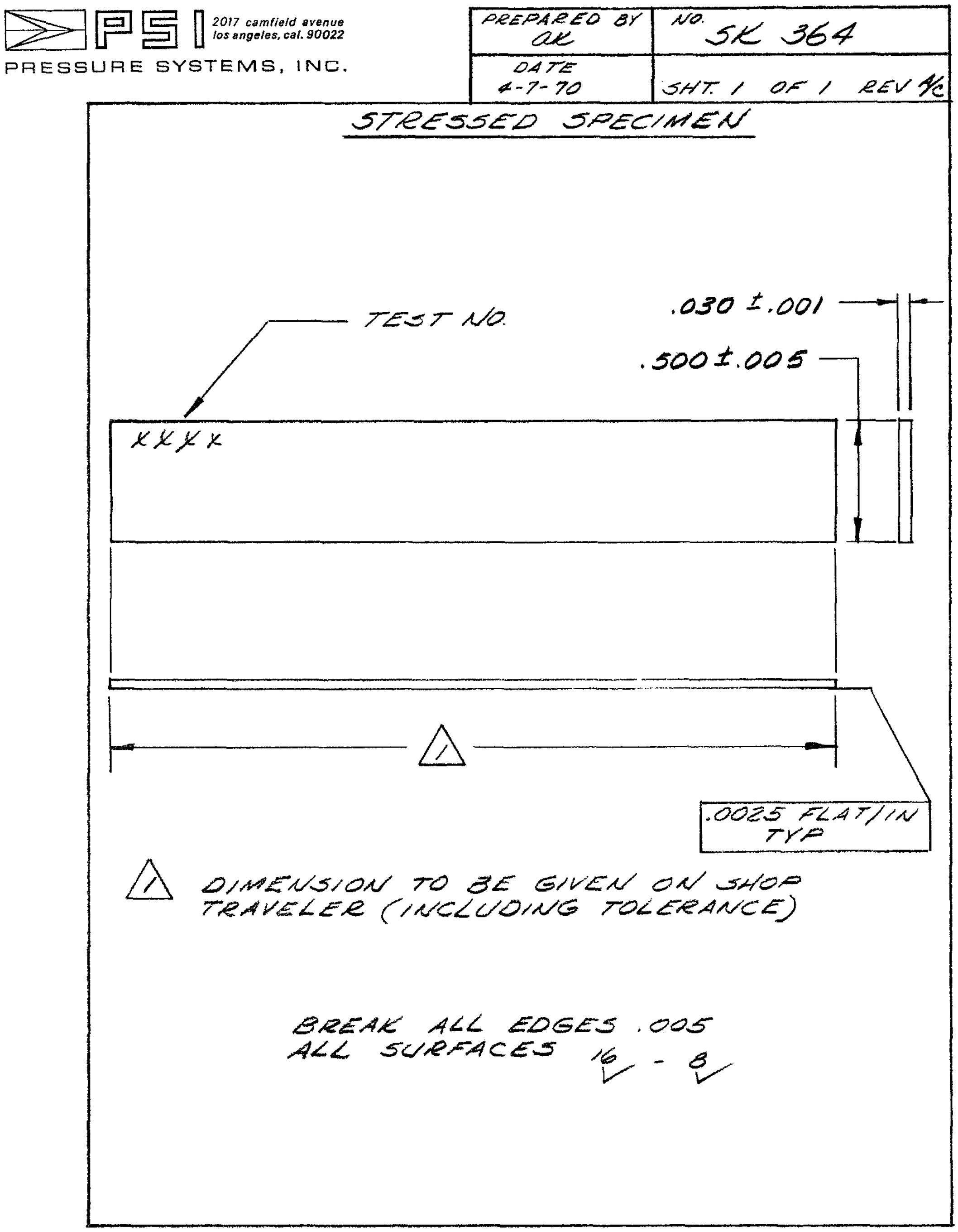

PSI
2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
AK
NO. SK 364
DATE
4-7-70
SHT. 1 OF 1 REV N/C
STRESSED SPECIMEN
TEST NO.
.030 ± .001
.500 ± .005
XXXX
1
.0025 FLAT/IN
TYP
1 DIMENSION TO BE GIVEN ON SHOP
TRAVELER (INCLUDING TOLERANCE)
BREAK ALL EDGES .005
ALL SURFACES 16 - 8

Figure 7

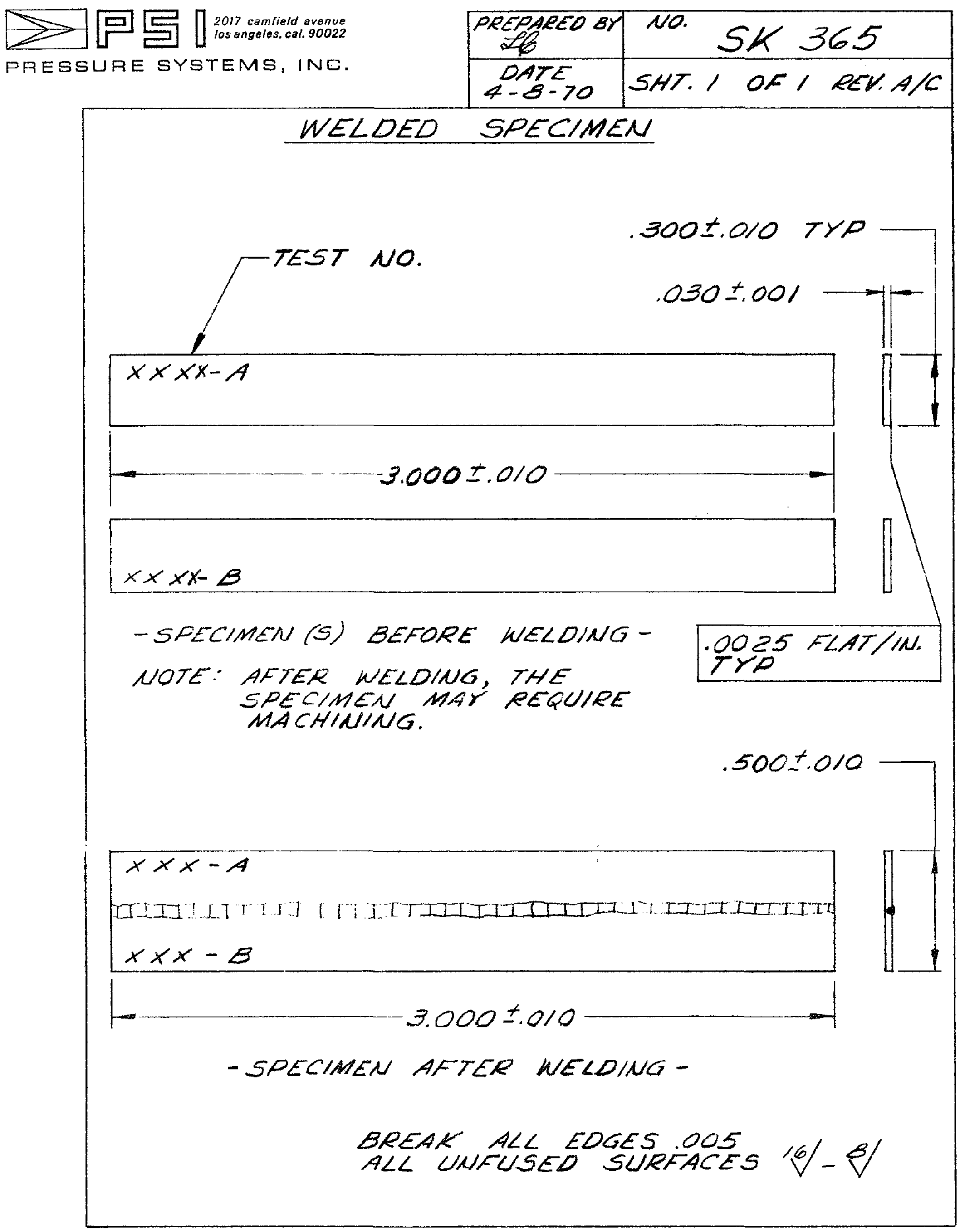

PSI 2017 camfield avenue los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
DATE 4-8-70
NO. SK 365
SHT. 1 OF 1 REV. A/C
WELDED SPECIMEN
.300±.010 TYP
TEST NO.
.030±.001
XXXX-A
3.000±.010
XXXX-B
-SPECIMEN (S) BEFORE WELDING-
.0025 FLAT/IN. TYP
NOTE: AFTER WELDING, THE SPECIMEN MAY REQUIRE MACHINING.
.500±.010
XXX-A
XXX-B
3.000±.010
-SPECIMEN AFTER WELDING-
BREAK ALL EDGES .005
ALL UNFUSED SURFACES 16/-8/

Figure 8

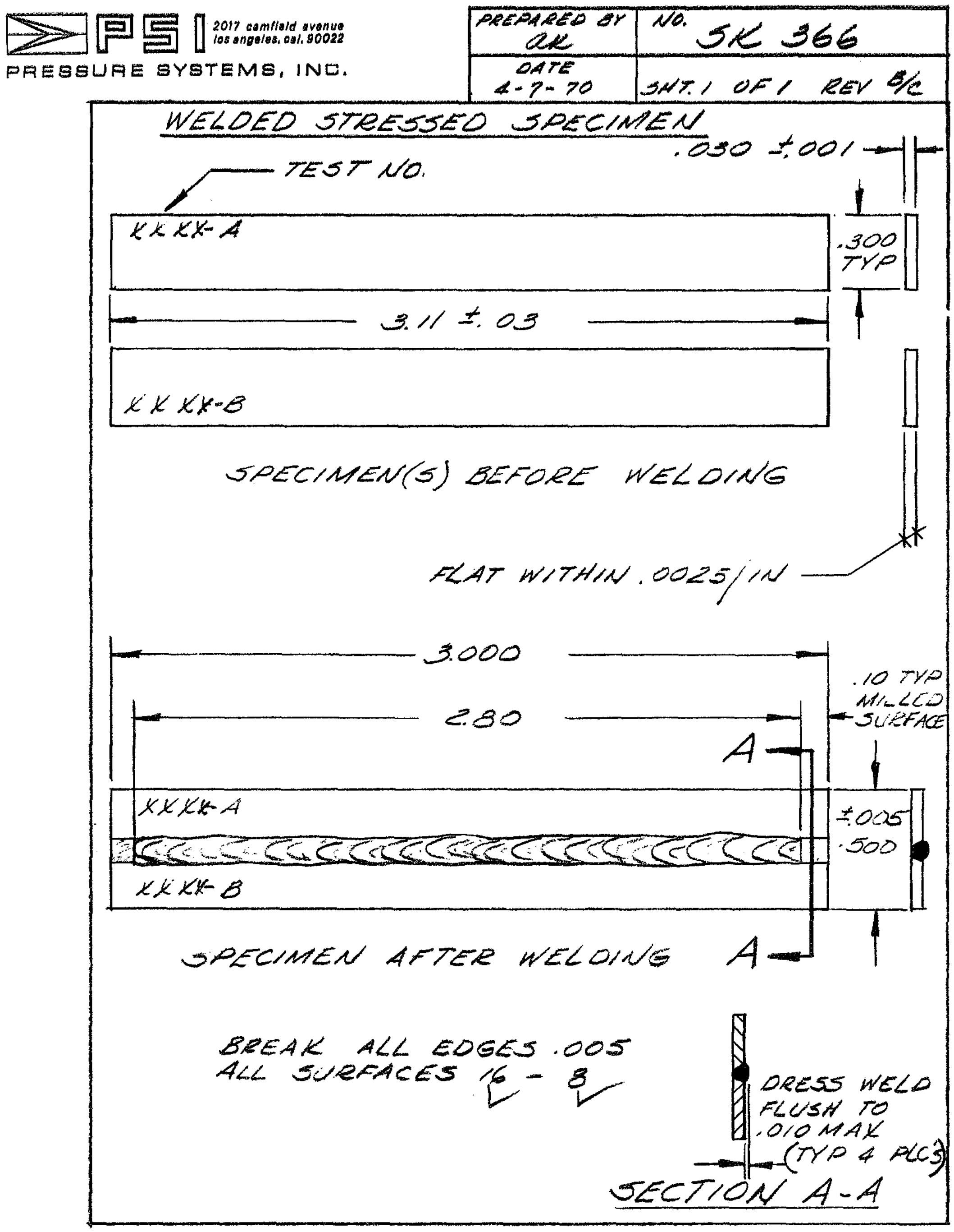

PSI
2017 camfield avenue
los angeles, cal. 90022
PRESSURE SYSTEMS, INC.
PREPARED BY
NO. SK 366
DATE
4-7-70
SHT. 1 OF 1 REV B/C
WELDED STRESSED SPECIMEN
.030 ±.001
TEST NO.
XXXX-A
.300 TYP
3.11 ±.03
XXXX-B
SPECIMEN(S) BEFORE WELDING
FLAT WITHIN .0025/IN
3.000
2.80
.10 TYP MILLED SURFACE
A
XXXX-A
±.005
.500
XXXX-B
SPECIMEN AFTER WELDING
A
BREAK ALL EDGES .005
ALL SURFACES 16 - 8
DRESS WELD FLUSH TO .010 MAX (TYP 4 PLCS)
SECTION A-A

Figure 9

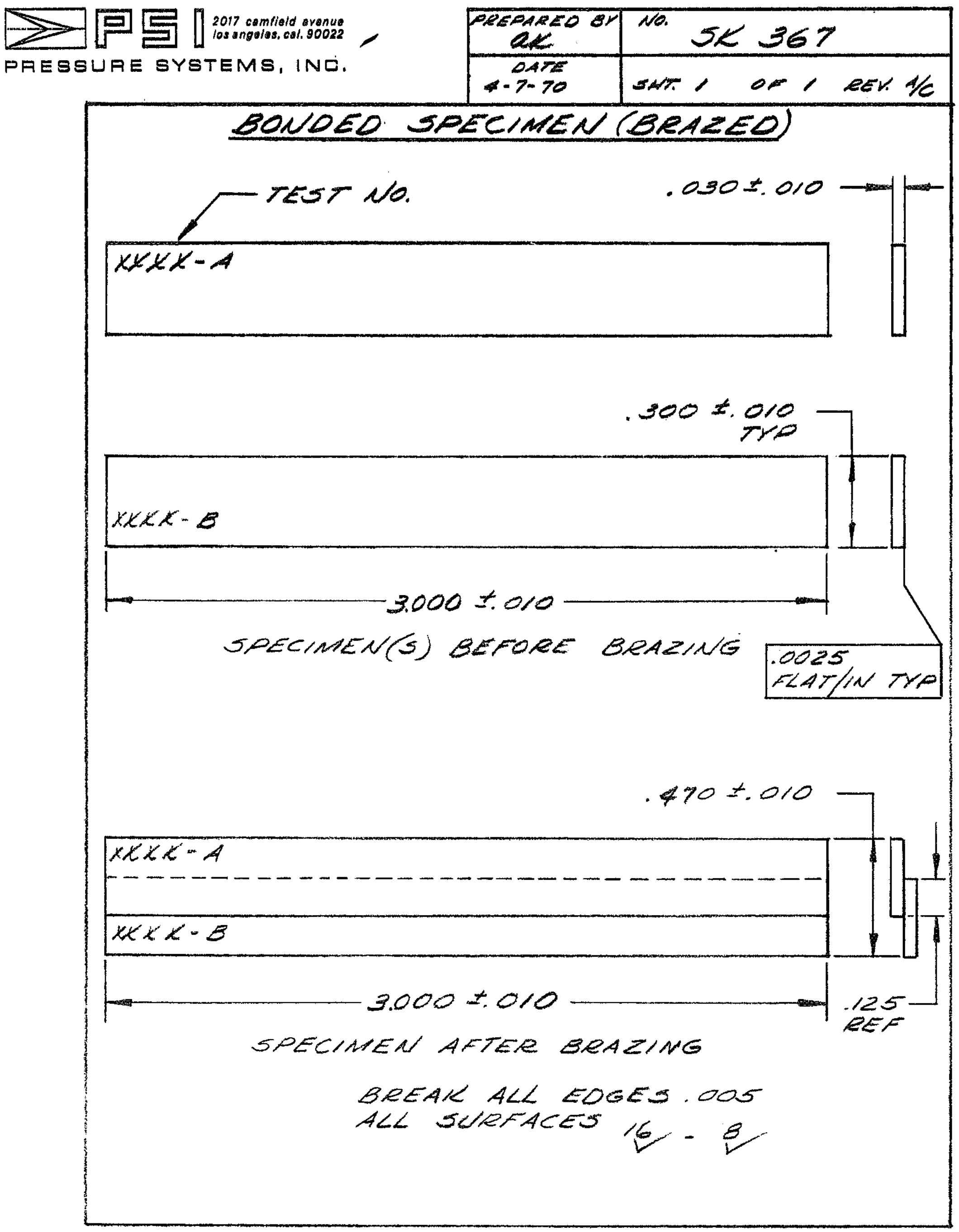

PRESSURE SYSTEMS, INC.
2017 camfield avenue
los angeles, cal. 90022
PREPARED BY
DATE
4-7-70
NO.
SK 367
SHT. 1 OF 1 REV. N/C
BONDED SPECIMEN (BRAZED)
TEST NO.
.030 ±.010
XXXX-A
.300 ±.010
TYP
XXXX-B
3.000 ±.010
SPECIMEN(S) BEFORE BRAZING
.0025
FLAT/IN TYP
.470 ±.010
XXXX-A
XXXX-B
3.000 ±.010
.125
REF
SPECIMEN AFTER BRAZING
BREAK ALL EDGES .005
ALL SURFACES 16 - 8

Figure 10

1.4 SUMMARY

This program proved the feasibility and developed the production techniques of producing in quantity compatibility capsule/transducers for the Long Term Compatibility Test Program. The methods and techniques of laying strain gages on the glass capsule, properly curing the gages, loading the specimen(s), fusing reducers, balancing and waterproofing the gages, calibrating the capsule/transducer, filling the capsule with a propellant and hermetically sealing the capsule/transducer are discussed.

The transfer of the in-house laboratory procedures developed by JPL into a commercial "production line" resulted in several basic problems. The solution to these problems and a detailed description of the special techniques developed by Pressure Systems, Inc. are thoroughly documented.

PSI delivered a grand total of 872 compatibility capsule/transducers, control capsules, and test capsules under this contract.

2.0 APPLICABLE DOCUMENTS

Jet Propulsion Laboratory:

JPL Specification No. 15013, Change M, dated 29 December 1960, Design Specification, Clean Room for Mechanical and Electrical Components.

JPL Specification No. 20000, Change A, dated 3 January 1954, Process Specification, Fusion Welding; and, Amendment No. 1, dated 22 January 1964.

JPL Specification No. GMO-50263-PRS, dated 22 January 1964, Process Specification, Fusion Welding of Aluminum and its alloys.

JPL Specification No. GMZ-50521-GEN-A, dated 24 February 1966, General Specification, Long Term Compatibility Testing with Hydrazine.

JPL Specification No. GMZ-50522-GEN, dated 22 April 1966, General Specification, Pressure Measurement System for Liquid Propellant Compatibility Testing.

JPL Reference Document, Test Report No. TR-32886, dated 17 April 1967, Pressure Measurement System for Liquid Propellant Compatibility Testing.

JPL Reference Document, Publication No. 951017, dated 17 April 1967, Hydrazine Compatibility Test Data System Specification Information.

JPL Specification No. FS 505029 dated 10 November 1969, Material Compatibility, Specimen/Capsules, General Specification for

JPL Specification No. FS 505030 dated 21 November 1969 Material Compatibility, Capsule/Transducers and Data Acquisition System, General Specifications for

JPL Procedure No. EP 504576 dated 3 September 1969 Long Term Compatibility, Test Specimen/Capsule Preparation for Hydrazine Service.

Drawing:

JPL 10030007 Test Capsule, Materials Compatibility Liquid Propellant, Type II.

Pressure Systems, Inc.:

PSI Procedure No. 65-000001, "Emergency Procedures for Hydrazine Handling"

PSI Procedure No. 65-000002, "PSI Safety and Handling Procedure for Loading Capsules with Hydrazine (N_2H_4) Propellant"

PSI Procedure No. 65-000003, "Handling and Emergency Procedures, Nitrogen Tetroxide (N_2O_4) Capsules"

PSI Procedure No. 65-000014, "Handling and Emergency Procedures, Monomethyhydrazine (CH_3NHNH_3) Capsules."

Military

MIL-W-16878D	Wire, Electrical, Insulated, High Temperature
MIL-B-7883	Brazing of Steels, Copper, Copper Alloys, and Nickel Alloys

3.0 GENERAL DISCUSSION OF TECHNIQUES EMPLOYED

3.1 Capsule/Transducer Preparation

Compatibility glass capsules were delivered to PSI without controlled annealing. Consequently, all glass capsules were annealed in the PSI Heat Treat Furnace (Figures 11 and 12). JPL instructed PSI as to the correct procedures in Technical Direction Memorandums (TDMs) No. 0015, 0016, 0040 and 0041. The critical step in the procedures was the rate of cooling of the glass after the anneal cycle, specified as 3°C/Minute, or less, to 500°C. Also, the time at elevated temperature was increased from 17 minutes to one hour.

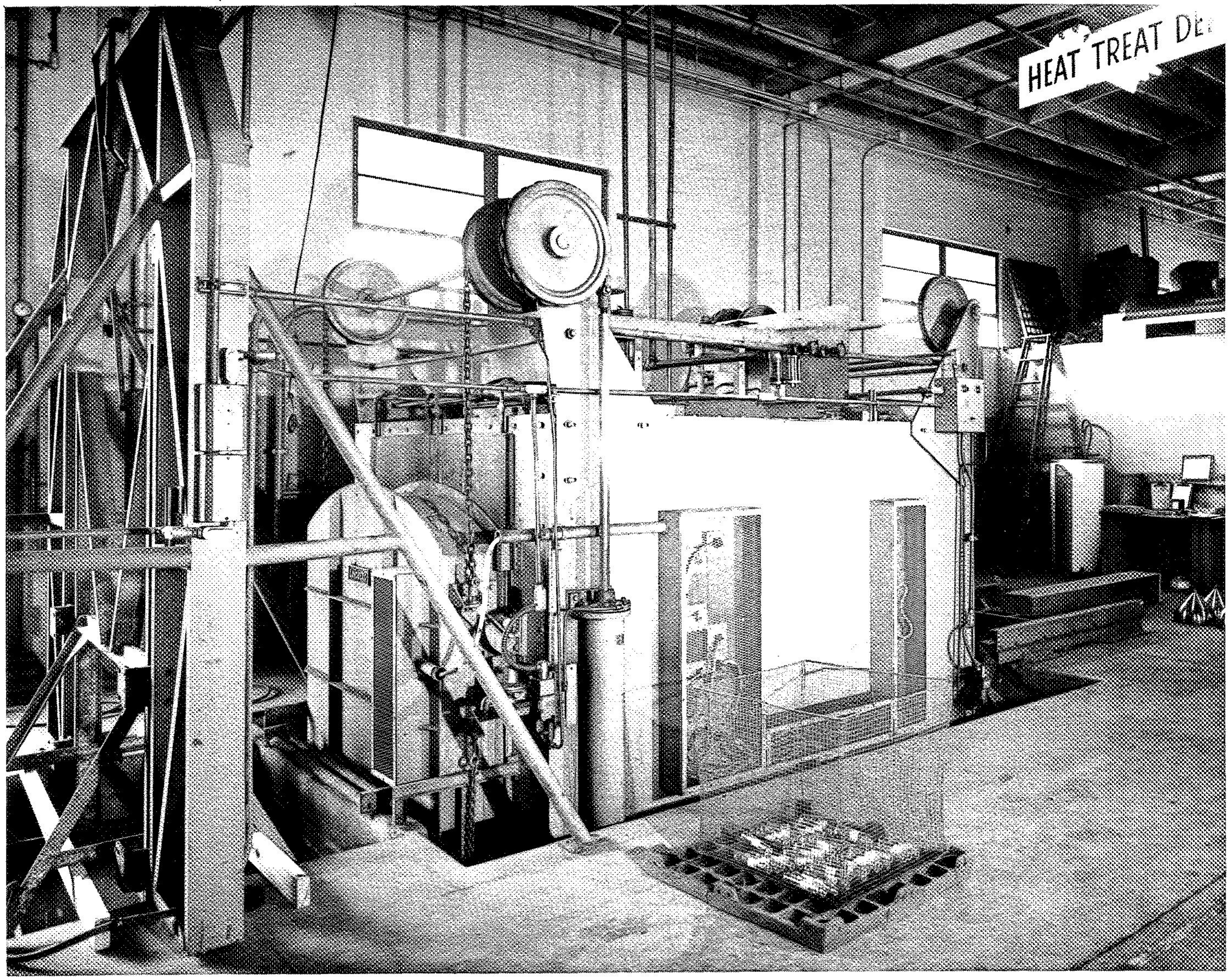
After annealing, each glass capsule was sandblasted to prepare a 1½" x 1½" square area for laying the strain gages. 400 grit aluminum oxide sand was used. Figure 13 shows this process, although the actual blasting was done inside of the protective tower.

Four strain gages were bonded to each capsule. Micro-measurements precision strain gages, model EA-06-250B6-120 were used. Initially, the strain gages were placed on a vacuum fixture (Figure 14) to hold them in proper orientation. In addition, one half of a TT-75 Terminal Strip (Source: Wm. T. Bean, Detroit, Michigan) was placed on the fixture.

Once in position, the gages and terminal strip are picked up using No. 600 Scotchbrand Transparent Tape to transfer to the glass capsule.

Prior to strain gage bonding, the glass capsules are cleaned thoroughly in an isopropyl alcohol vapor degreaser (Figure 15).

BLH Electronics, Inc. EPY-150 two part epoxy cement was used to bond the strain gages to the glass capsules. Several capsules were coated with adhesive from one epoxy packet.

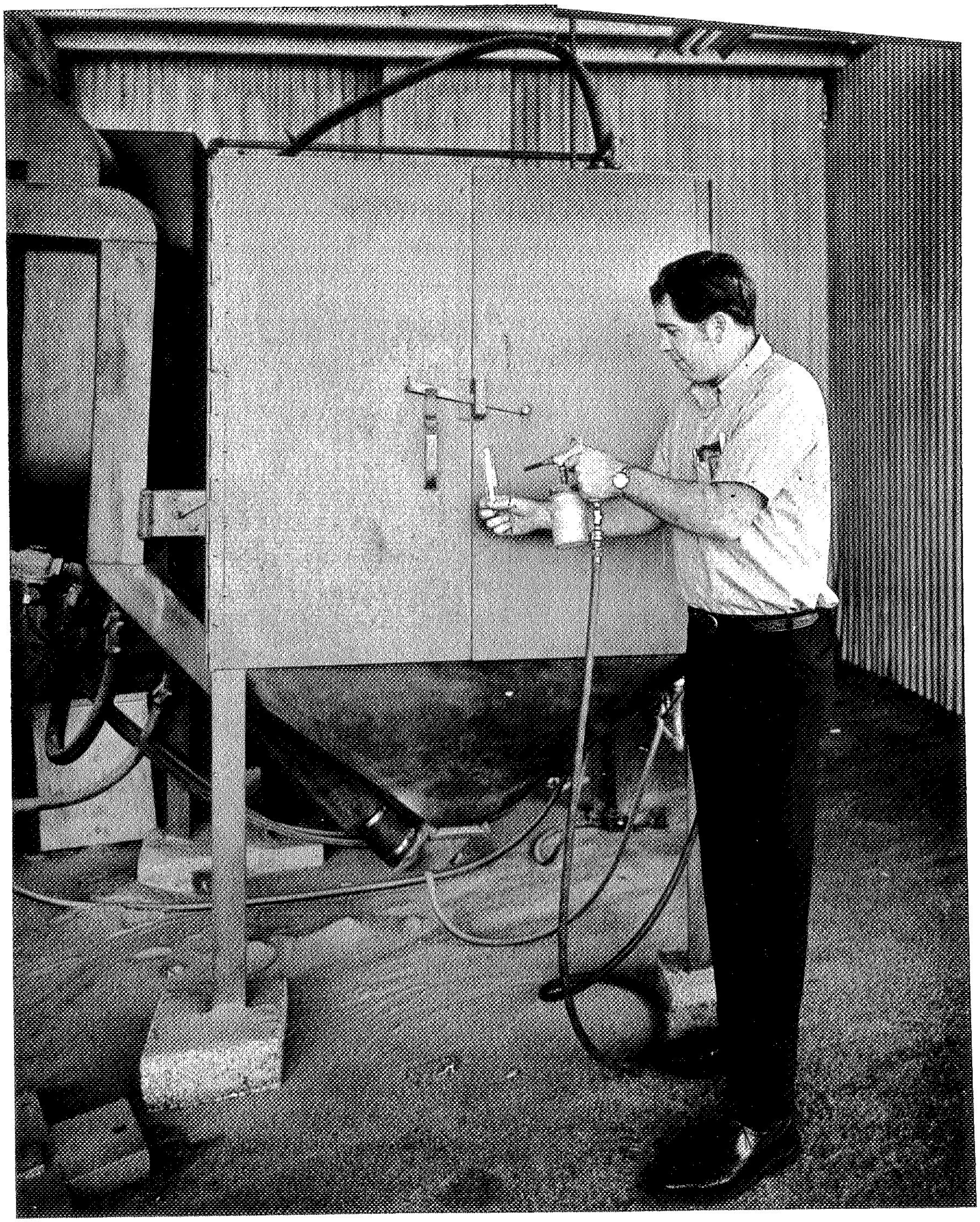


FURNACE USED FOR ANNEALING GLASS CAPSULES

Figure 11

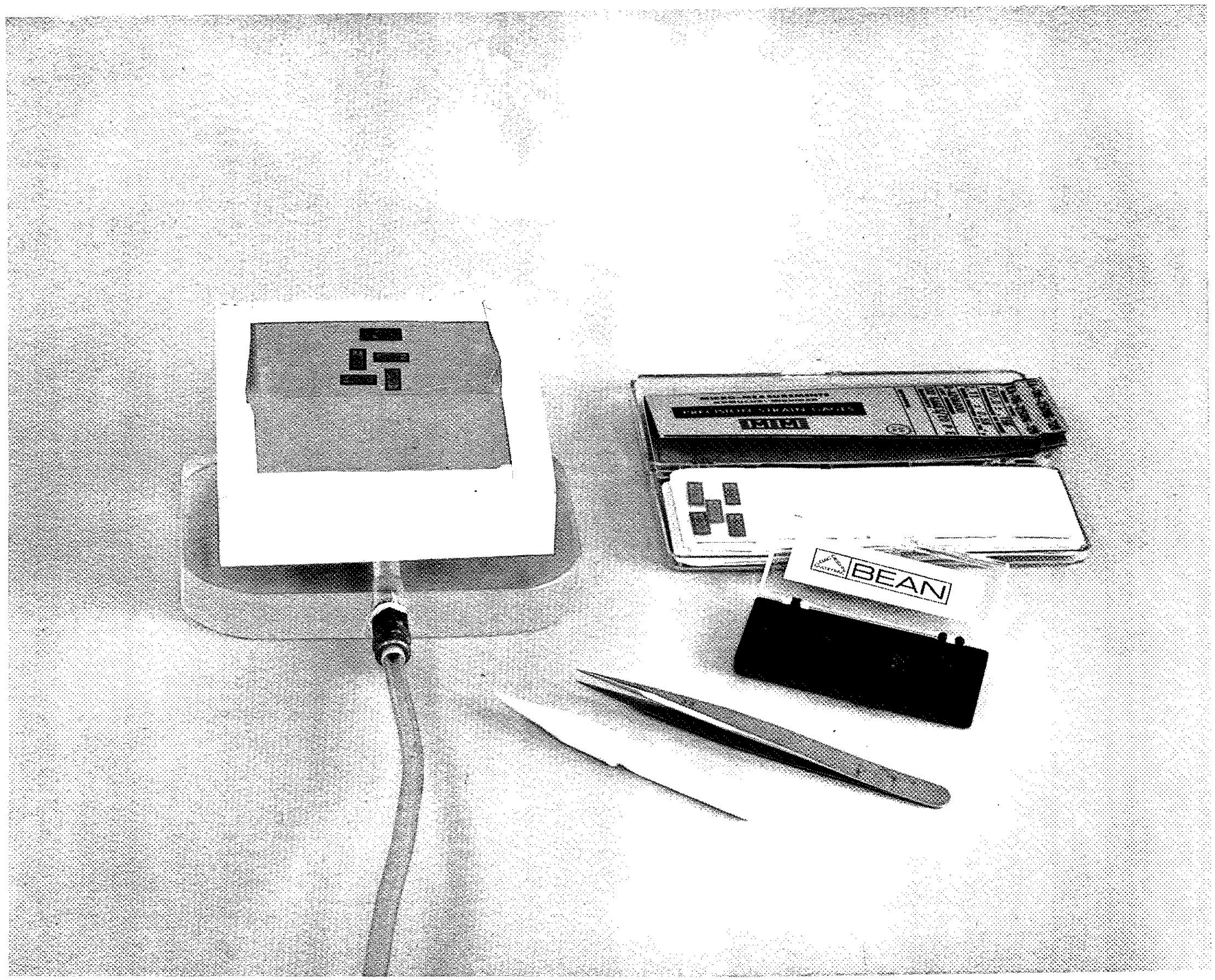
FURNACE CONTROLLER

Figure 12



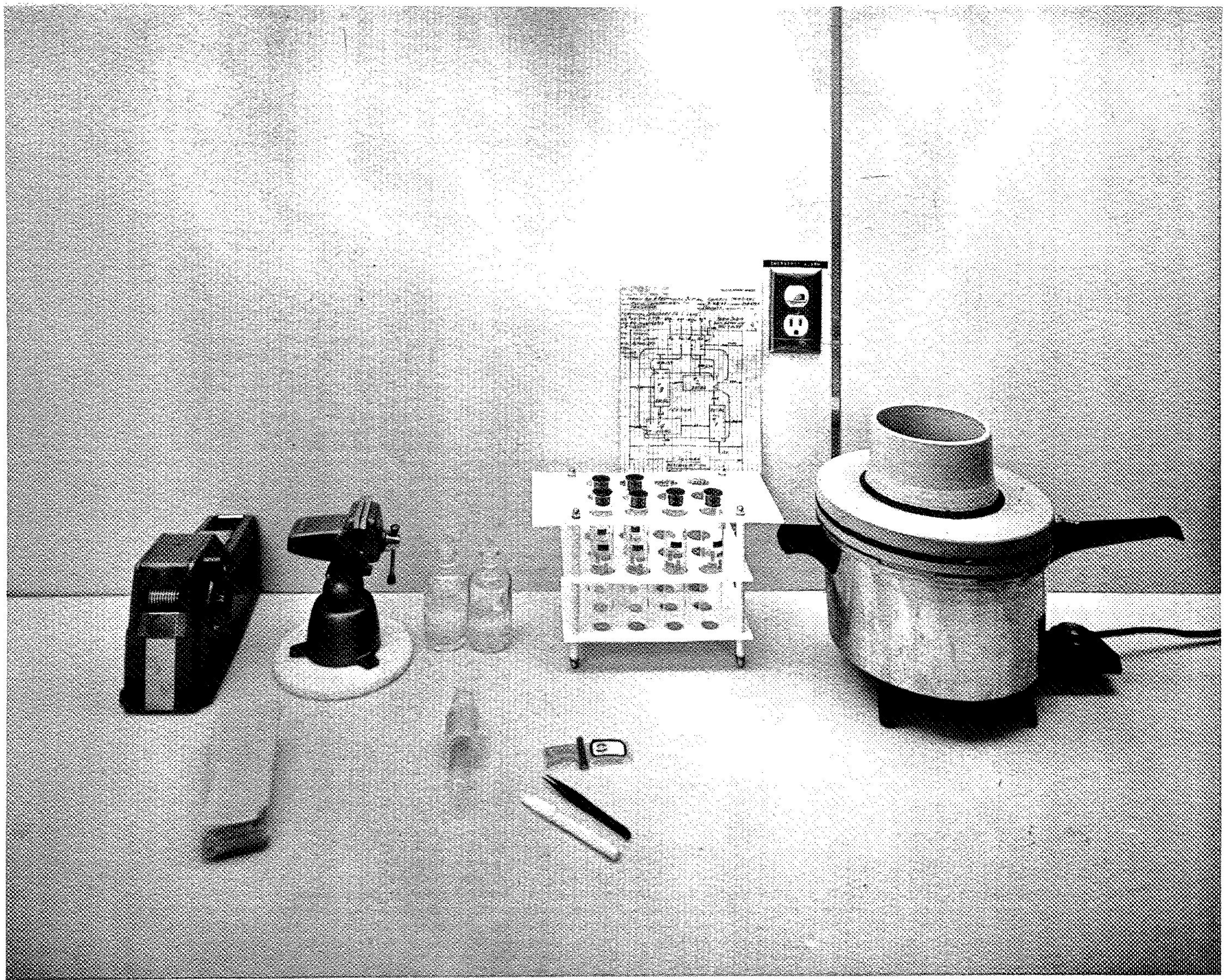
SAND BLASTING CAPSULES

Figure 13



STRAIN GAGE ASSEMBLY EQUIPMENT

Figure 14



STRAIN GAGE BONDING EQUIPMENT

Figure 15

After the gages coated with cement were placed on the capsule, a silicone gum wrapper was stretched around the capsule to clamp the strain gages firmly to the glass capsules using 5 to 15 psi clamping pressure. Cellophane tape was used to hold the silicone gum wrapper in place while the cement cured. (Equipment used in this manufacturing procedure are shown in Figure 15). After the strain gages are cemented to the glass capsule, the cement is cured at elevated temperature in an air circulated oven (Tenney Engineering, Inc. Model T.M.U.F.-3-100511; Leeds and Northrup Speedomax 6 No. 69800 Temperature Recorder; and Honeywell, Inc. Type R7161 Temperature Controller). This equipment is shown in Figure No. 16.

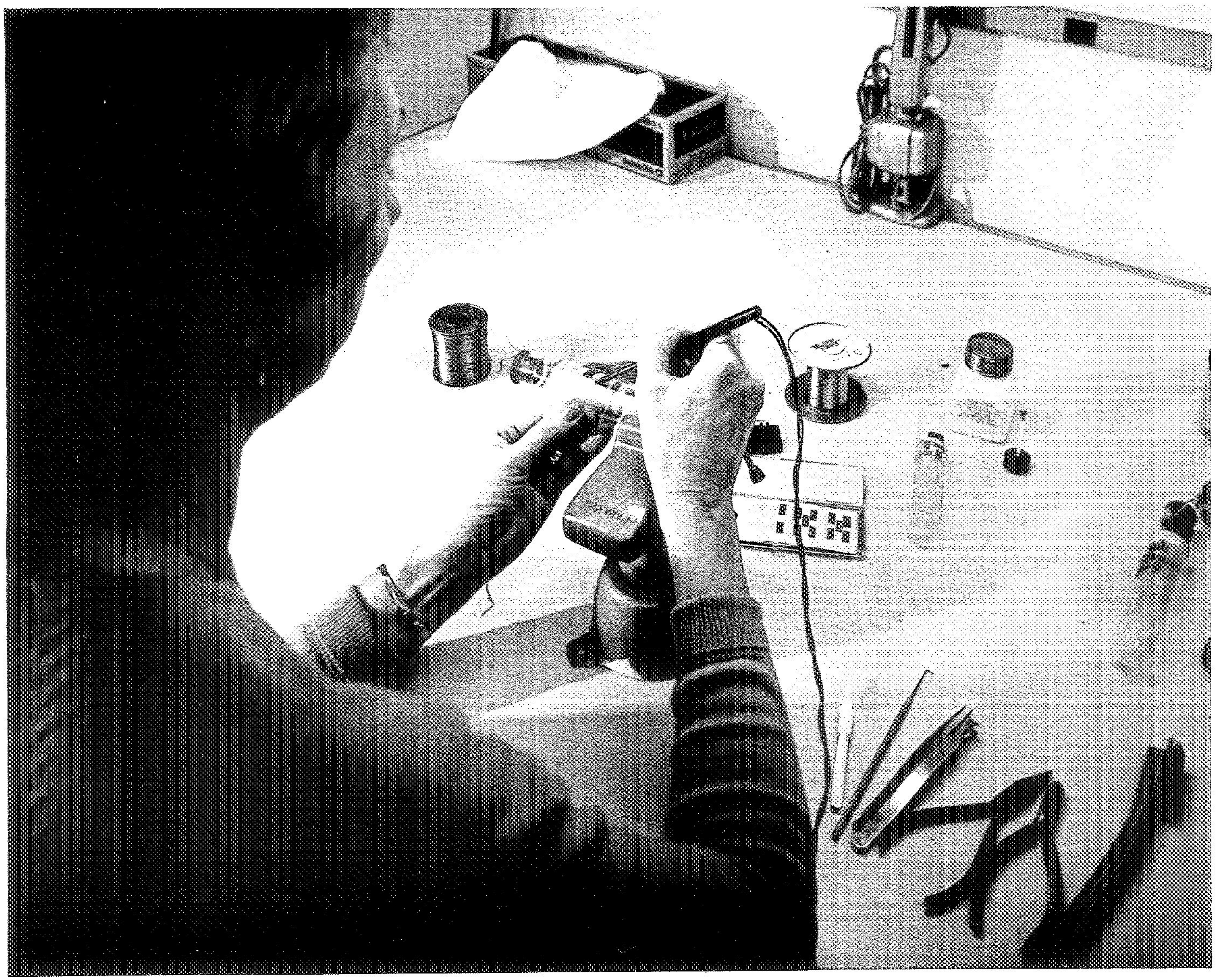
Subsequent to curing of the bonding cement, the strain gages are soldered into a complete full bridge network. As shown in Figure 17, great care is required to insure that thermal stresses are minimized in each soldered joint. Only certified technicians (Appendix II) were used for this operation to produce acceptable capsule/transducers. Figure 18 shows equipment used in this operation. After the capsules were soldered and inspected, the bridge wires were anchored down using Gagekote No. 4 Silicone-Phenolic Resin Water-Proofing Material (Source: Wm. T. Bean).

After this step, the glass capsule is post cured in the air circulated oven for 3 hours at + 200°F, followed by 17 to 18 hours at + 150°F.

After post cure, each capsule is pre-calibrated to verify suitable output sensitivity of the strain gage bridge. A PSI designed pressure control panel was used for this operation, shown in Figure 19. The panel consists of a Universal Electronics Model Q5-8-4AM power supply to provide the 5 VDC excitation voltage and a Dynamics Instruments Co. Model 1362R Microvolt Meter.

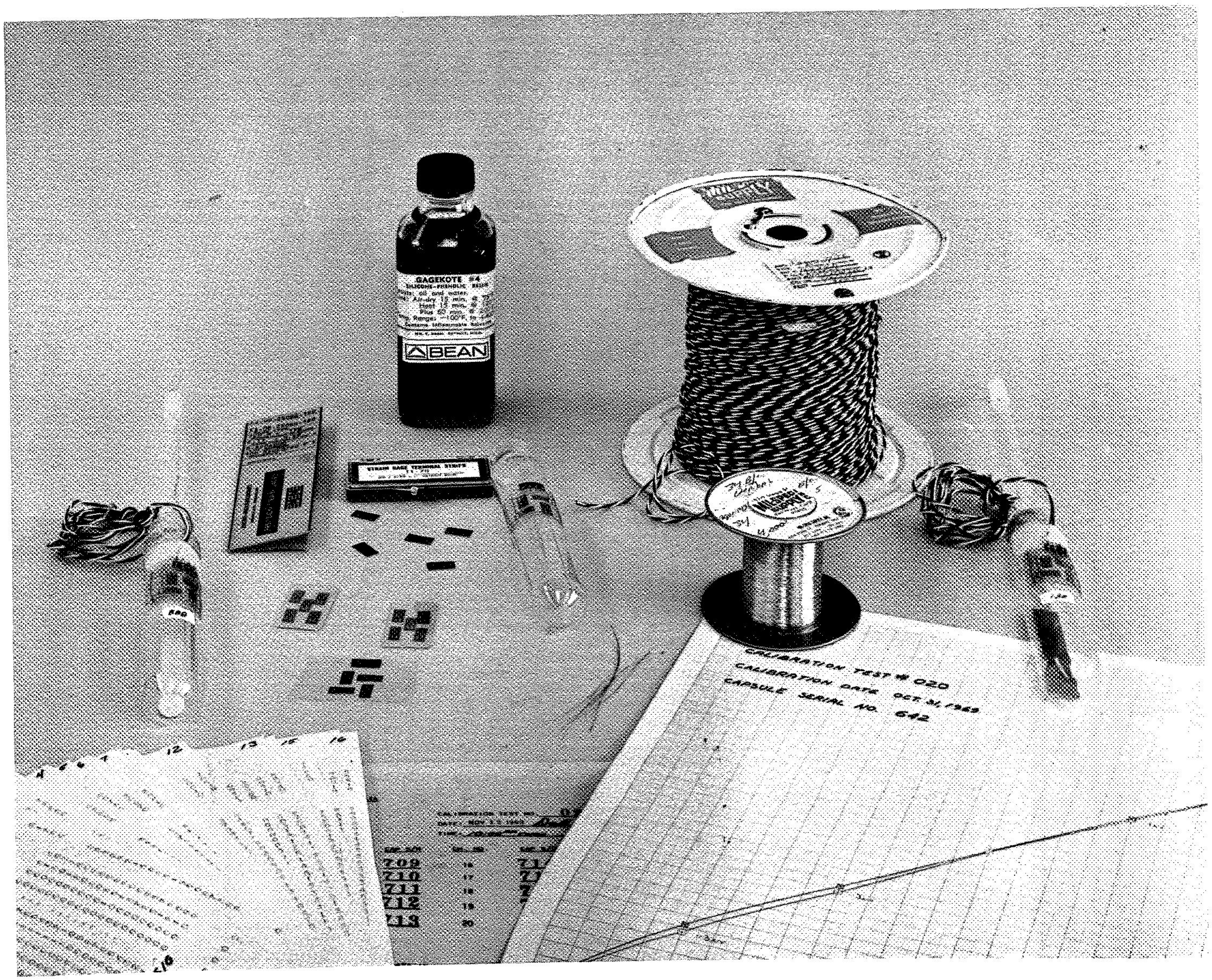
The capsule/transducer is now placed in a plastic storage container in stock ready for subsequent operations of loading the material compatibility specimen(s).

AIR CIRCULATED CURING OVEN
Figure 16



WIRING STRAIN GAGES

Figure 17



MATERIALS USED IN COMPLETING CAPSULE/TRANSDUCER SYSTEM

Figure 18

PRE-CALIBRATION PROCEDURE
Figure 19

3.2 Specimen Preparation

Types and quantity of compatibility test specimens used for this program were delineated by JPL in tables detailing the basic material and the test type. For example, 6AL-4V titanium was a basic material that could be used in seven types of test, specifically, as a slug; a bi-metallic contact specimen; a bi-metallic separated specimen; a stressed specimen (to 67% of yield); a welded specimen; a brazed specimen; or a coated specimen (with six (6) different coating materials called out).

Specimens were carefully controlled to ensure traceability. The material name, alloy designation, specification number, producer, chemical composition, heat number, metallurgical state, and processing history were determined prior to further compatibility specimen processing (similar data, where available, was determined for non metallic specimens). This information was assembled into data packages that accompanied each test capsule delivered to JPL/ETS.

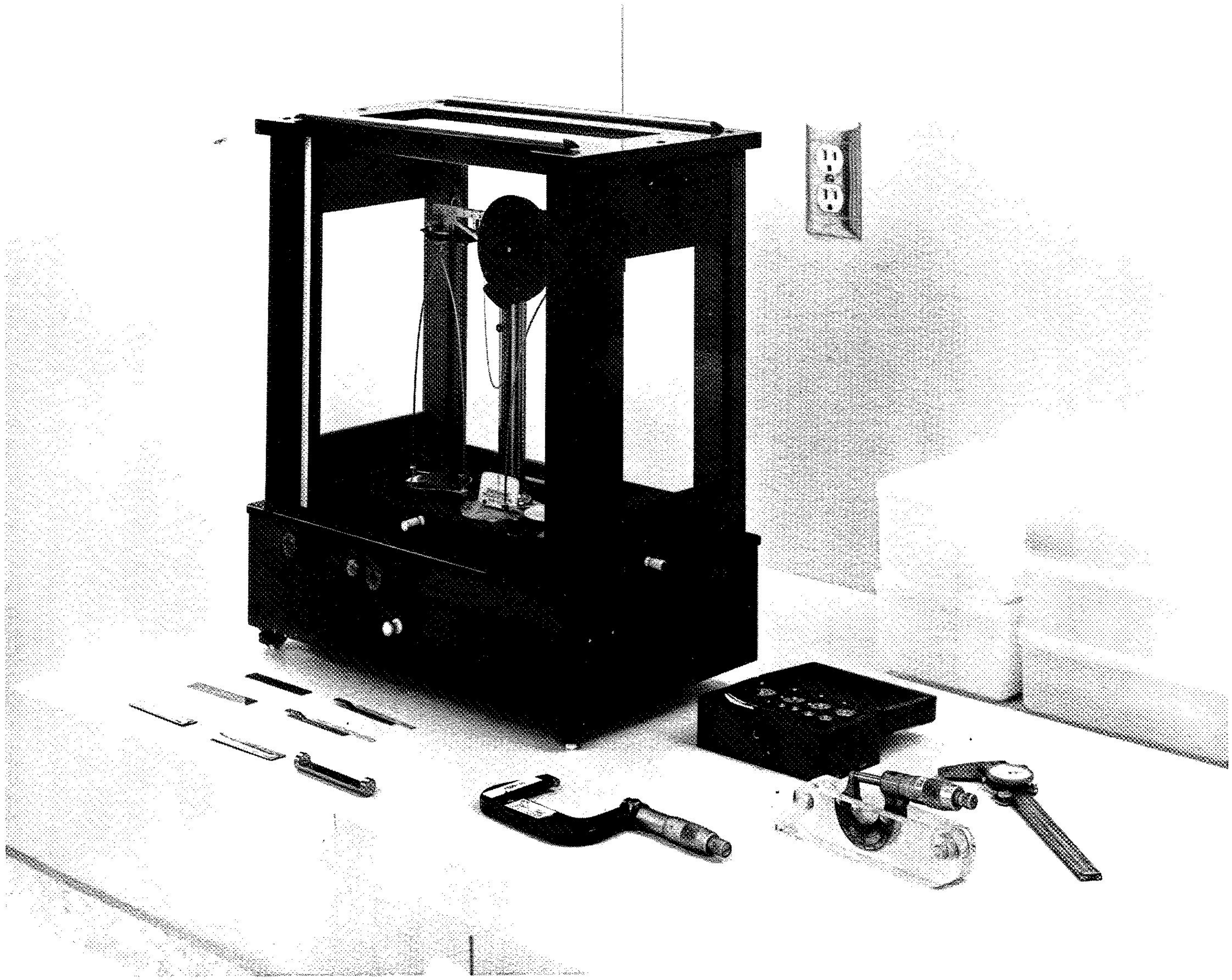
Specimens were ganged and held in a "soft jaw" mill fixture for milling of edges. After inspection, specimen edges were milled to print dimensions. After additional inspection, specimens were double disc ground on the flat surfaces.

To eliminate contamination in double disc grinding, all grinding wheels were dressed, the machines completely cleaned and new coolant used. Special masks, thinner than the specimen, were used to hold the specimens in place.

Following double disc grinding, the edges were lapped by the outside vendor. Subsequent to PSI receiving inspection, a final edge lap was made to ensure print finish on each edge.

All specimens were then Vibraetched with the specimen test number, bagged and prepared for subsequent operations (see Figure 2).

Subsequently, all physical dimensions, weight and surface finish were obtained and recorded (Figures 20, 21 and 22).

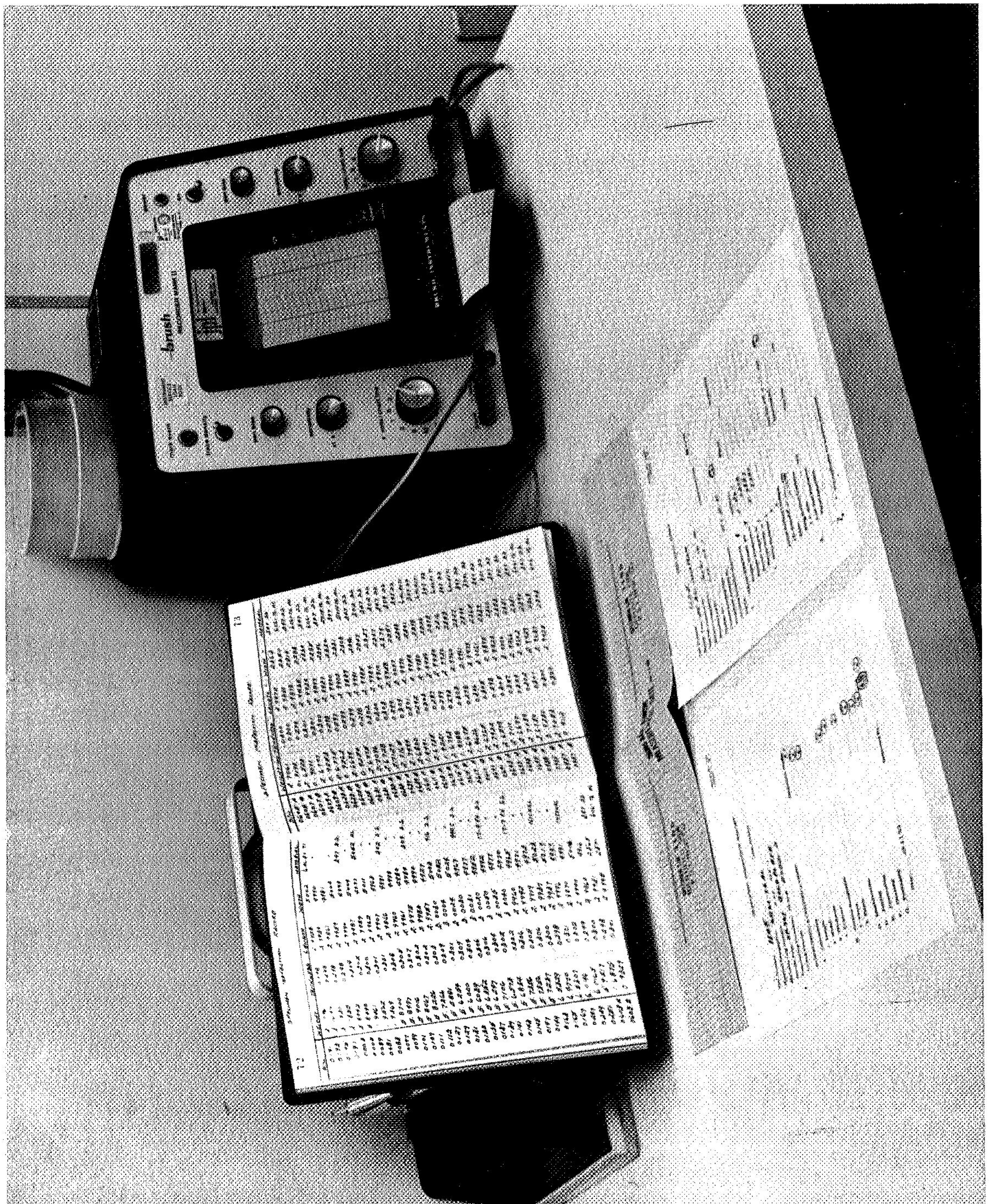


PREPARATION OF MATERIAL COMPATIBILITY SPECIMENS

Figure 20

SURFACE FINISH MEASURING EQUIPMENT

Figure 21



RECORDING SPECIMEN DATA

Figure 22

3.3 Loading the Specimen

After proper cleaning (discussed in detail in paragraph 4.8) the specimen(s) is loaded into a glass capsule and a glass reducer section fused to the open end of the capsule. This glass blowing operation was conducted using a special tool (PSI-403) built for this operation. Essentially this is a small glass blowing lathe with six degrees of control to ensure proper mating of the reducer section to the capsule, while holding essential tolerances. To prevent excess heat from causing thermal stresses in the strain gage area, wet asbestos was wrapped around the strain gage area (Figure 23).

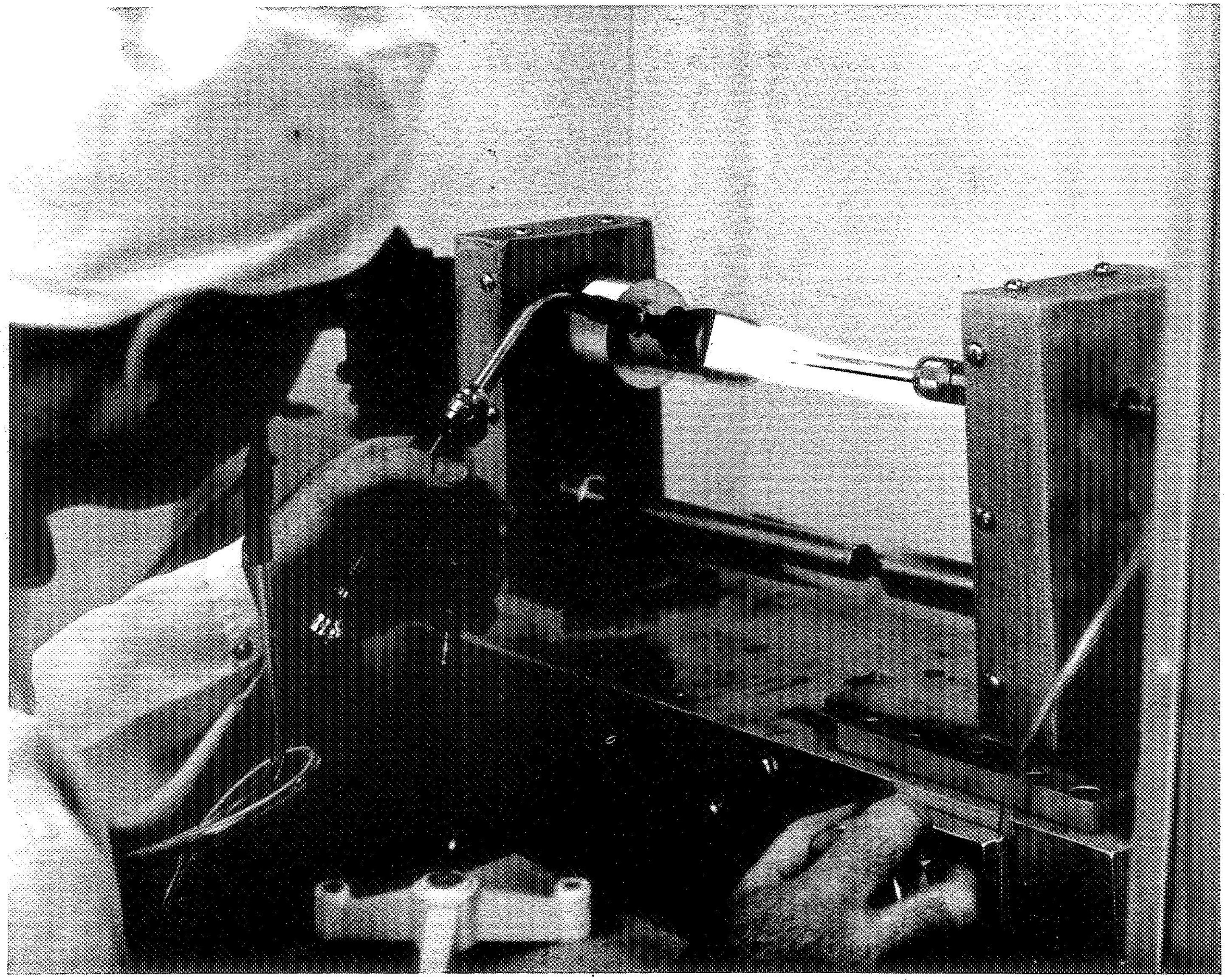
After the glass fusing operation, the fused neck area was inspected with a Bethlehem 3" Polariscope (Figure 24) to verify absence of highly stressed areas and confinement of any residual stresses to a small localized area. Additionally, a vacuum leak test was made using a Model BD-10 high frequency generator. If the glass had a pinhole, the charge would arc at the pinhole.

Subsequent to the above operation, the capsule/transducer (loaded with the material specimen) is calibrated. A special JPL furnished Data Acquisition System (for description refer to JPL Specification GMZ-50522-GEN) was used to obtain strain gage output at pressures ranging from 0 to 64 psia, to determine zero shift and acquire data to plot strain gage sensitivity (output in microvolts versus psia). Figure 25 shows the Data Acquisition System and associated calibration equipment. Figure 37B shows a typical data sheet.

3.4 Propellant Filling

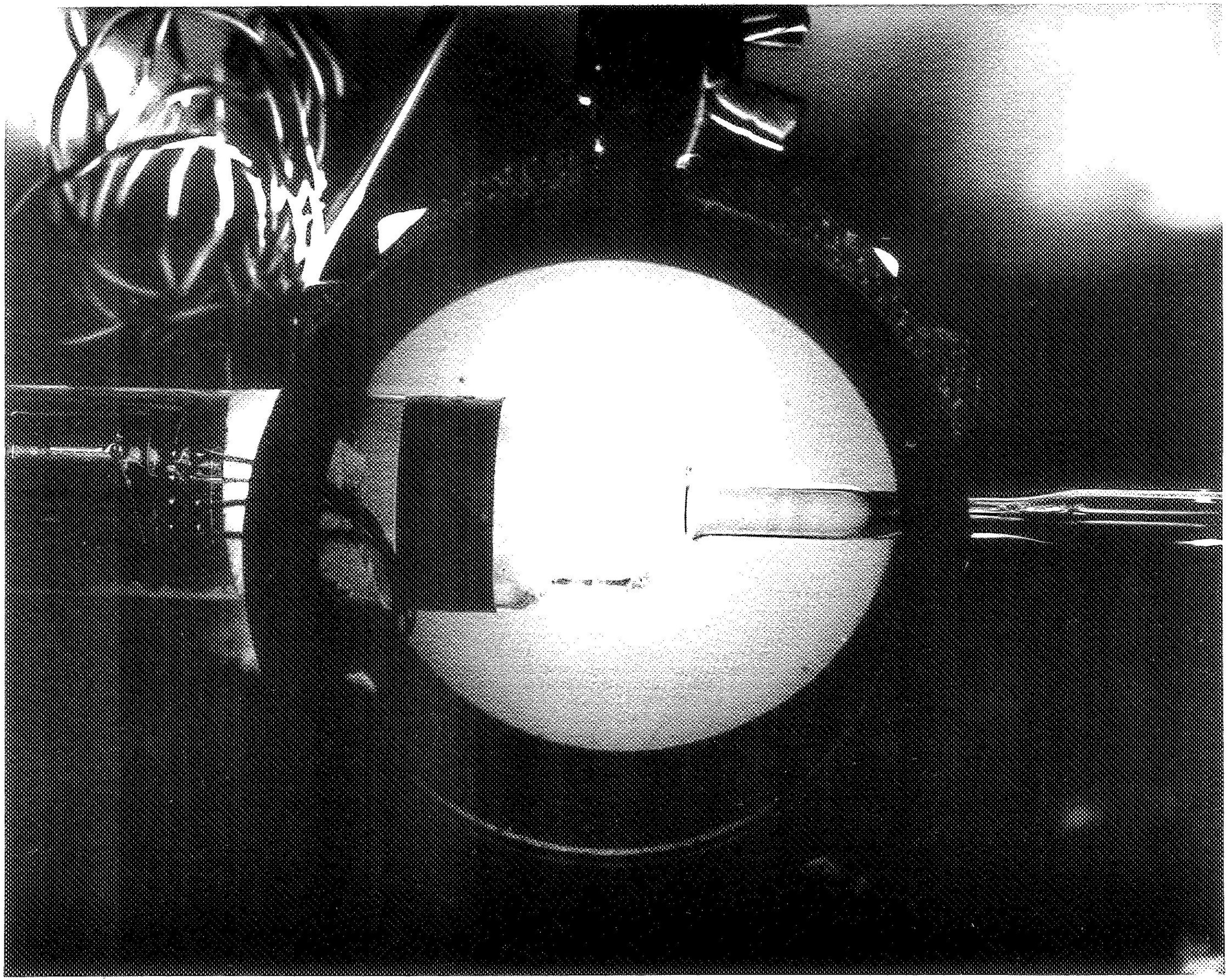
After calibration, a polyethylene protective wrapper was placed around the strain gauges (TDM 0055). The capsule/transducer was then ready to be filled with 20 cubic centimeters of the selected propellant. PSI filled capsules with one of three propellants, hydrazine (N_2H_4), nitrogen tetroxide (N_2O_4) or monomethylhydrazine (MMH). JPL filled all capsules designated for Hydrazine-Hydrazine Nitrate (N_2H_4-$N_2H_5NO_3$). (Table IV propellant).

As discussed in Section 4.12 careful safety precautions were observed by PSI personnel in handling propellants.



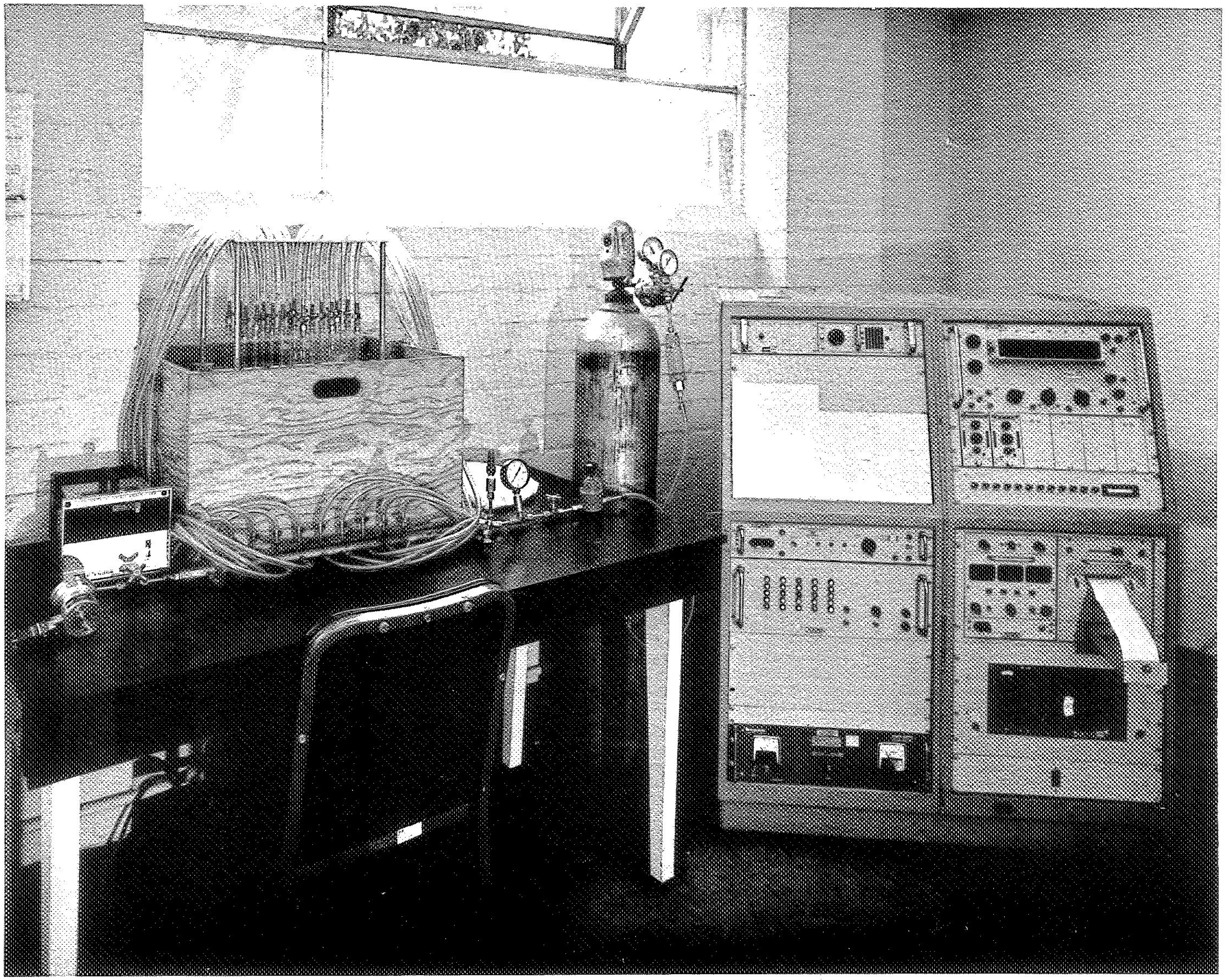
AFTER LOADING SPECIMEN, REDUCER SECTION IS FUSED TO GLASS CAPSULE

Figure 23



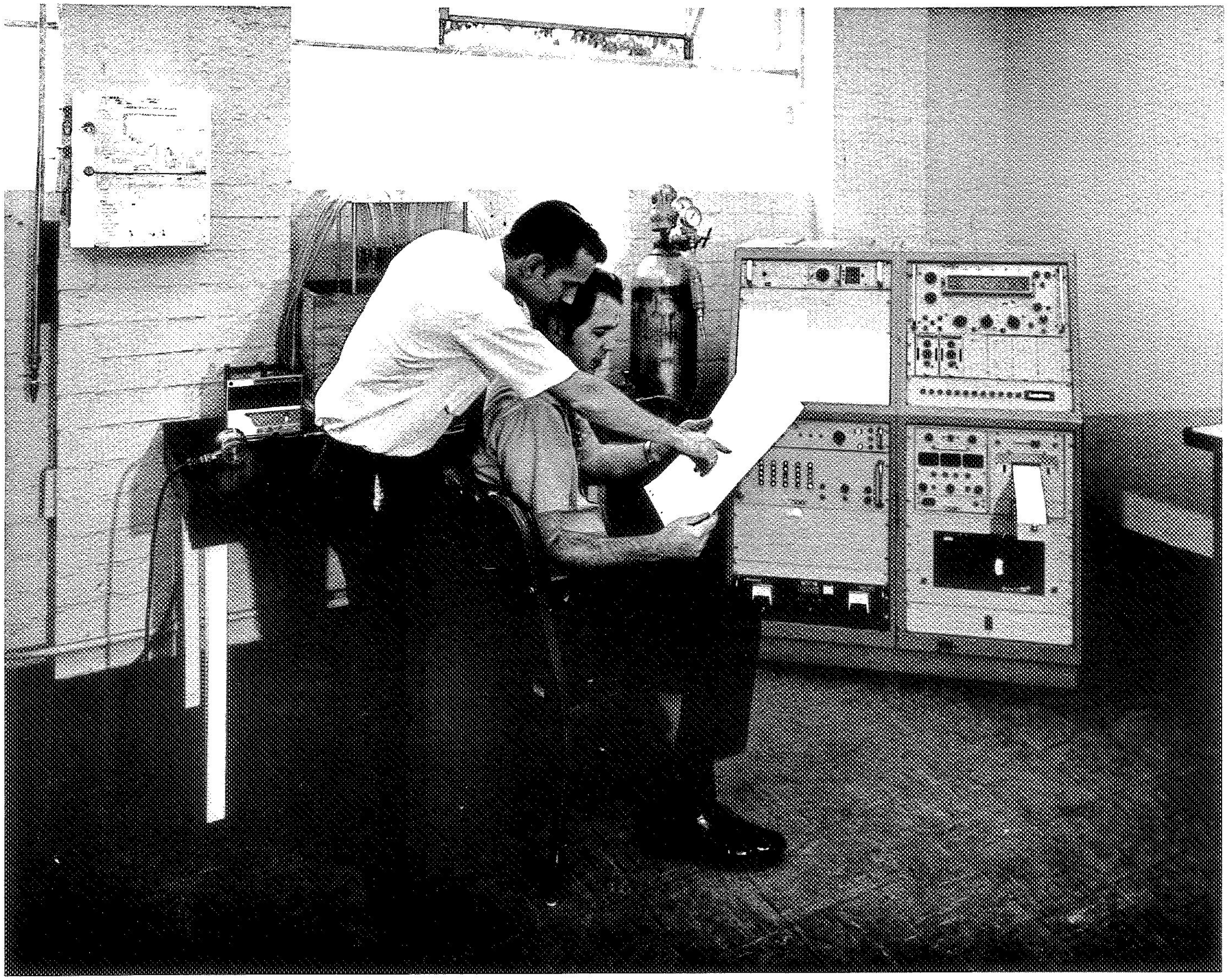
CHECKING GLASS FUSING OPERATION WITH A POLARISCOPE

Figure 24



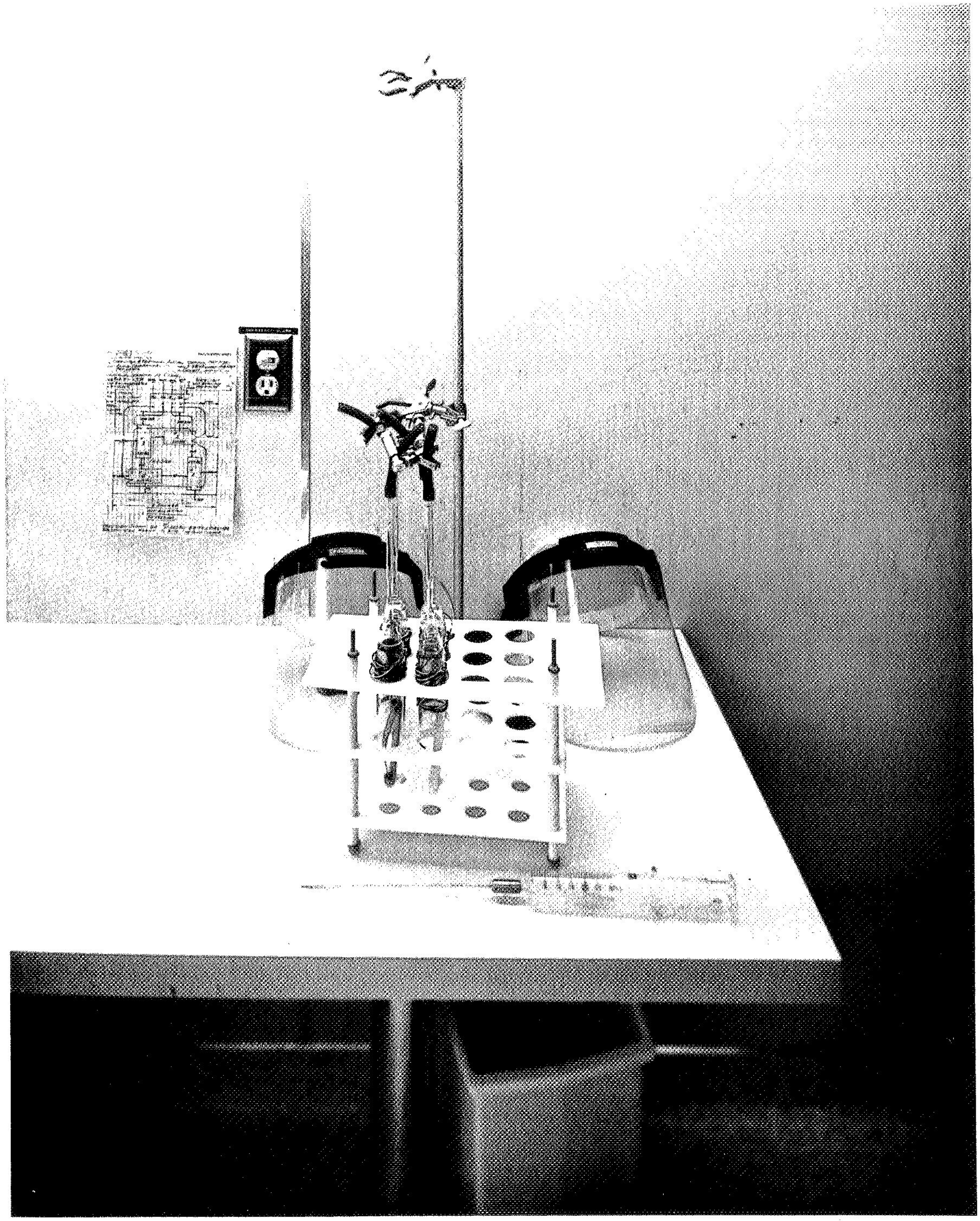
CAPSULE CALIBRATION SET UP

Figure 25



ANALYZING CALIBRATION DATA

Figure 26



PREPARING CAPSULES FOR PROPELLANT FILLING
Figure 27

Figure 27 shows capsule/transducers ready for filling with propellant. Special teflon handling racks are used in processing the capsules.

In actual practice, the capsules were filled with propellants under the explosion proof fume hood in the Clean Room Trailer. Figure 28 shows the glass syringe and stainless steel tube used in the filling operation. The 50cc glass tip syringe (Becton Dickinson & Co.) had a 300 series stainless steel capillary tube (9" x 1/16" ID) attached to fit into the capsule/transducer.

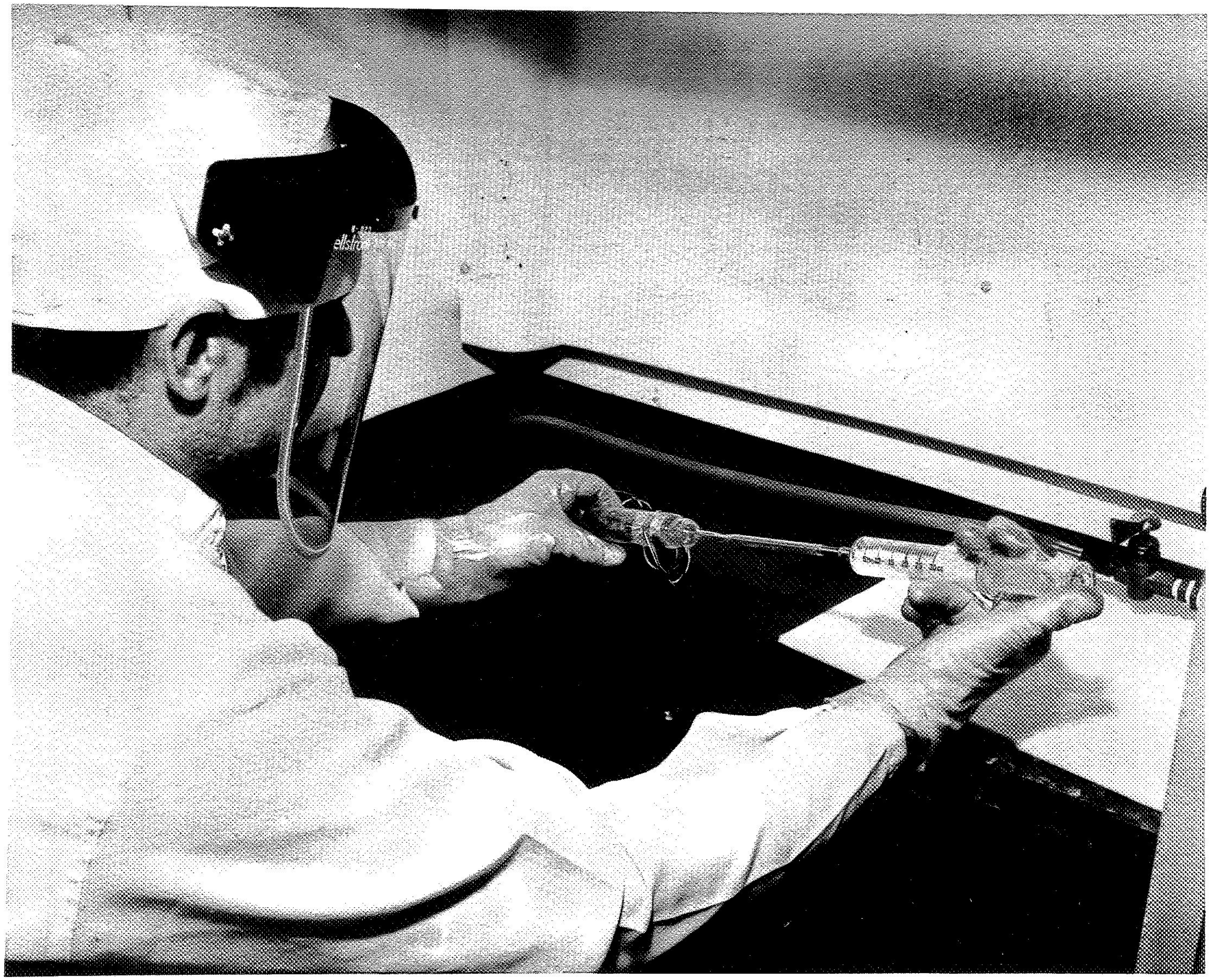
After filling, the capsule/transducers are sealed with rubber tubing and a pinch cock. The propellant is frozen in a dry ice and alcohol slurry (for hydrazine and monomethyl-hydrazine) or quick frozen in liquid nitrogen (for nitrogen tetroxide). (Figure 29)

When the propellant was frozen (Figure 30), the capsule/transducer was evacuated to 0 psia with a vacuum pump (Figure 31) and then hermetically sealed (Figure 32) using an oxy-propane torch.

A completed hermetically sealed capsule is shown in Figure 33.

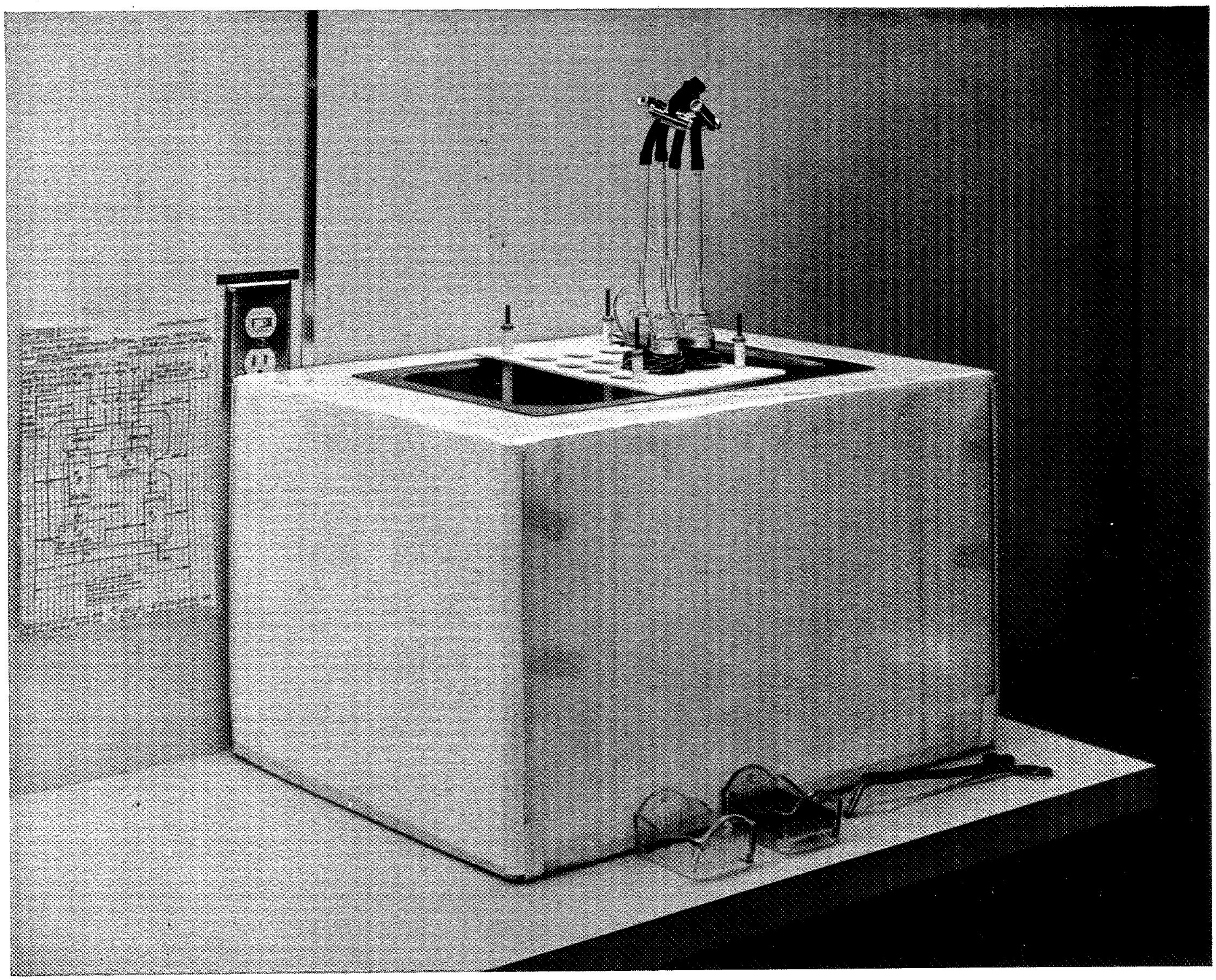
3.5 Capsule/Transducer Shipping

The sealed capsule/transducer is returned to the slurry to maintain the propellant in a frozen state. The frozen capsules were then placed in JPL's Transportation Container (JPL P/N D911-7307) and maintained in a frozen state while shipped to JPL's Edwards Test Station in the Mojave Desert. A typical shipment normally had approximately forty (40) capsule/transducers and four (4) control capsules.



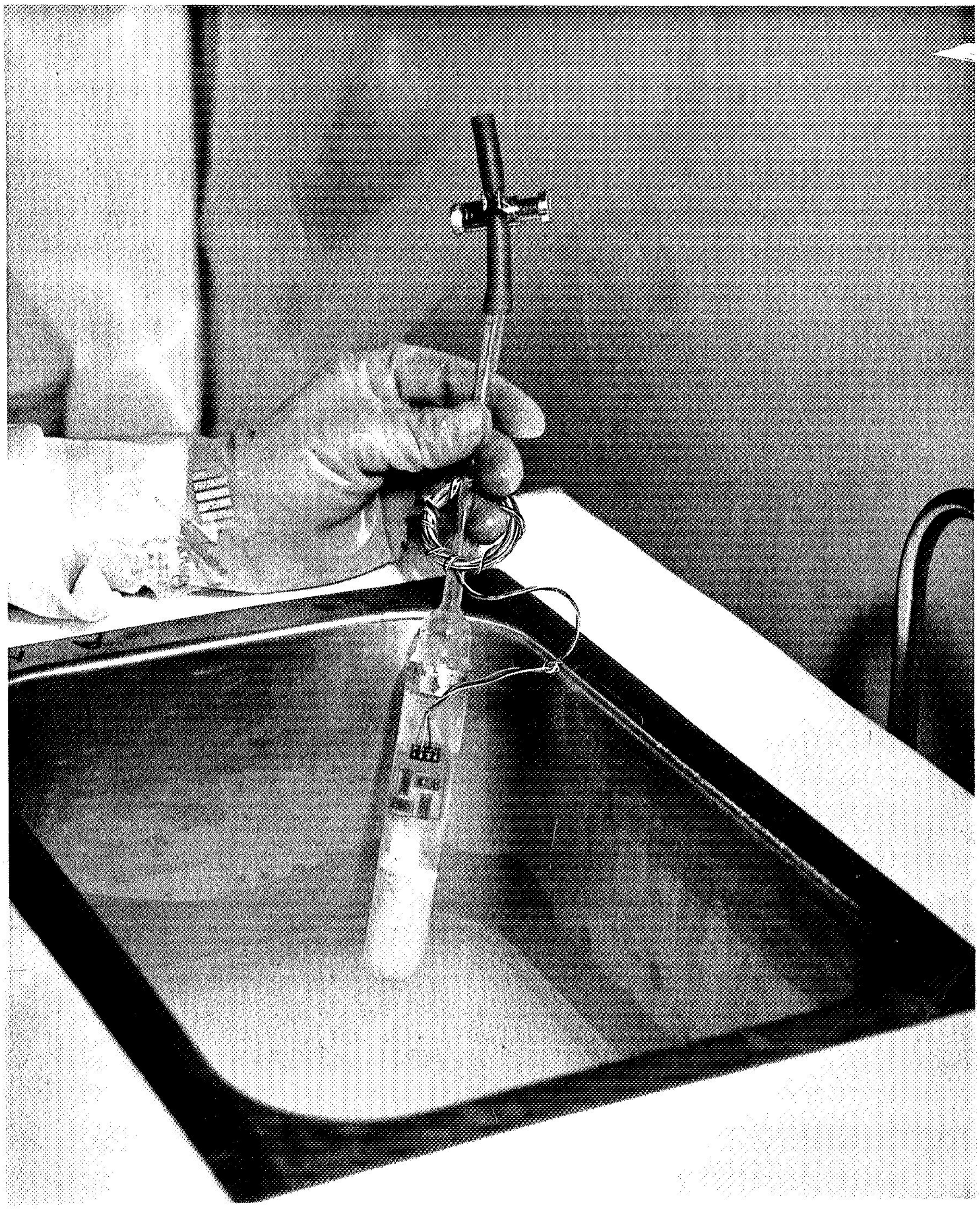
PROPELLANT FILLING OPERATION

Figure 28



PROPELLANT FREEZING OPERATION

Figure 29

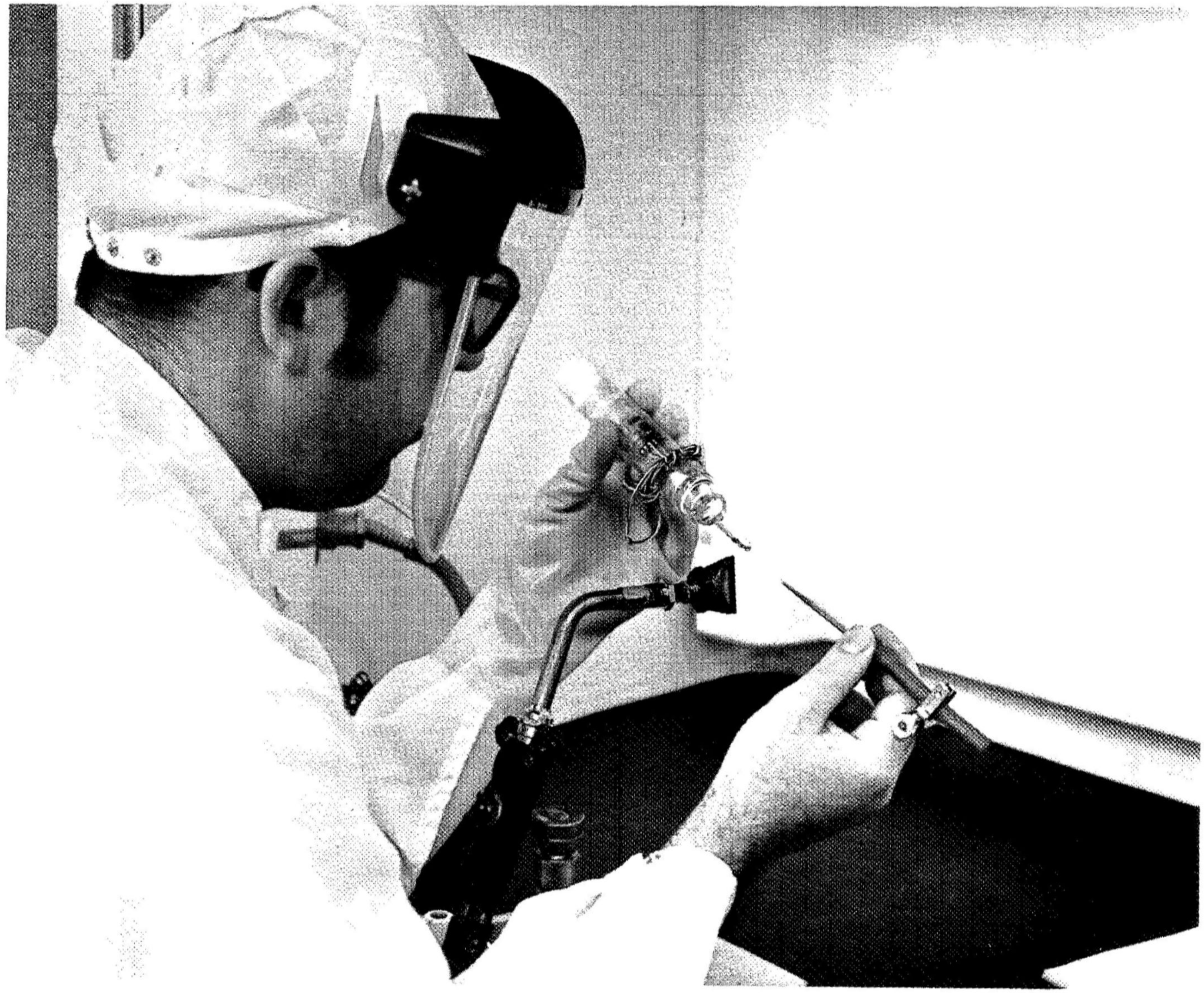


CAPSULE/TRANSDUCER WITH FROZEN PROPELLANT

Figure 30

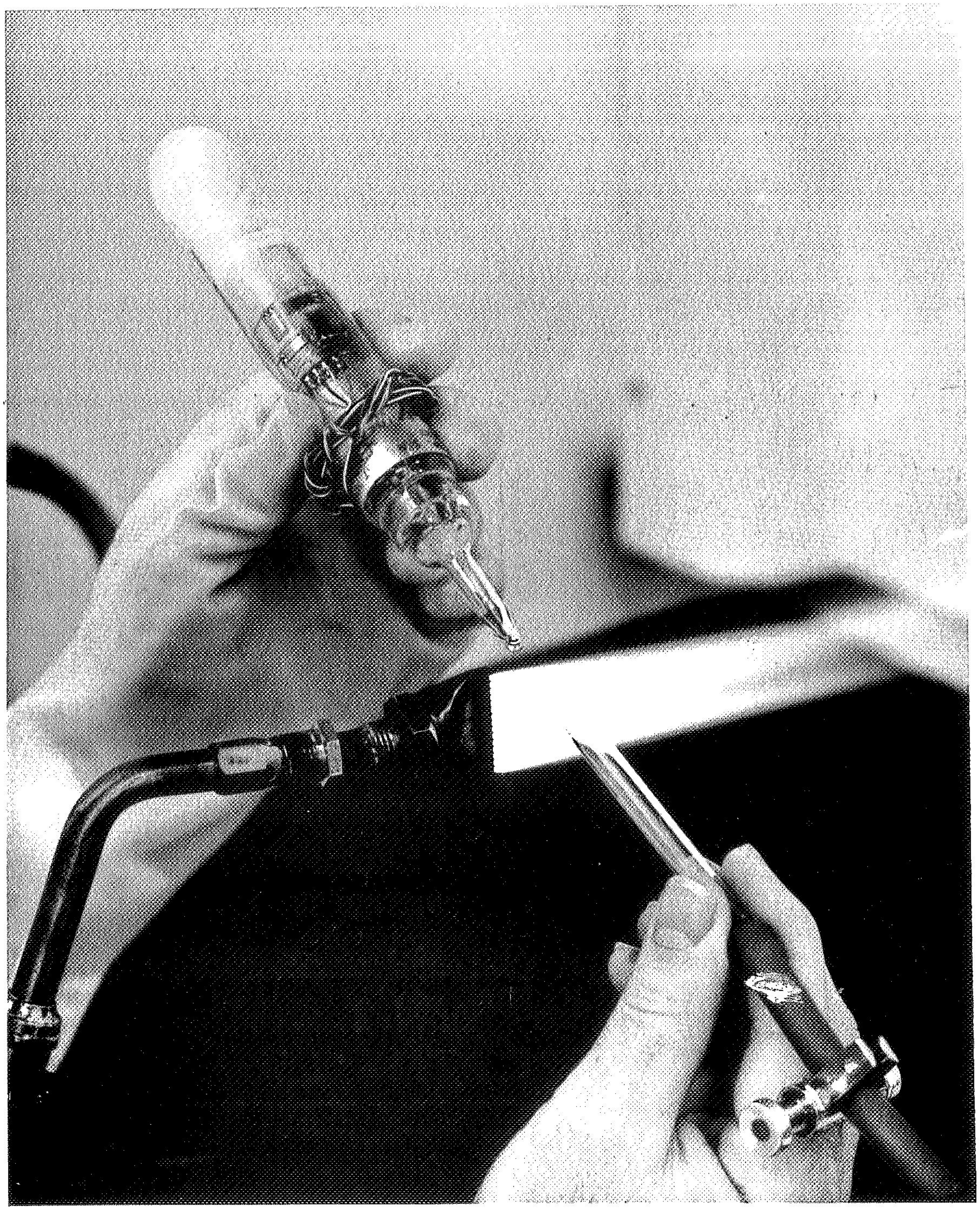
EVACUATING CAPSULE/TRANSDUCER TO 0 psia

Figure 31



HERMETICALLY SEALING CAPSULE/TRANSDUCER

Figure 32



SEALED CAPSULE/TRANSDUCER READY FOR SHIPPING

Figure 33

4.0 SPECIFIC DISCUSSION OF TECHNIQUES EMPLOYED

The following discussion will avoid repeating procedures and requirements delineated in JPL documents (Paragraph 2.0) and will concentrate on specific PSI techniques that amplify those procedures.

PSI cooperated with JPL in their writing the latest documentation package concerning the procedures developed under this contract, specifically: (1) JPL Procedure No. EP 504576 dated 3 September 1969, (2) JPL Process Specification FS 505029 Rev. A dated 10 November 1969 and (3) JPL Process Specification FS 505030 Rev. A dated 21 November 1969 (Paragraph 2.0).

4.1 Glass Handling Techniques

Annealing batches of glass capsules was accomplished as discussed in Paragraph 3.1 above and in compliance with referenced JPL Procedure and JPL General Specification as modified by TDMs No. 0015, 0016, 0040 and 0041. Batches of 250 glass capsules were placed horizontally in stainless steel baskets for the annealing operation. The Data Acquisition System was used to record temperature output of four (4) thermocouples placed in the furnace. Thermocouples were located inside a capsule on each layer of the basket. Recorded data was analyzed to verify compliance with the annealing temperature (575°C) and that the cooling rate did not exceed 3°C per minute 500C.

The art of glass blowing was taught to the PSI technician by a qualified JPL glass blower. Once qualified by the JPL professional, PSI followed the procedures recommended. The principal innovation used by PSI was developing Tool No. 403, a glass blowing "lathe." (See Figure 23) This device enabled the reducer to be moved relative to the capsule in all degrees of freedom. Thus the normal imperfections in the glass could be adjusted and a repeatable reducer-capsule joint made. After the joint was made, a constriction was placed in the reducer tube to aid in the final hermetic sealing operation. Figures 32 and 33 show the set up for hermetically sealing the glass capsules.

Great care was taken in making this final seal to insure that the propellant was frozen. If the hydrazine were allowed to liquify and reach suitable chemical conditions, it could have exploded. Handling the nitrogen tetroxide was less hazardous from an explosion point of view, but could have produced a greater toxic problem if an accident had occurred. (See Paragraph 4.12). No accidents of any kind occurred during this program.

4.2 Strain Gage Assembly Procedures

Strain gage assembly was modified during the program to reflect improved techniques and to provide more accurate procedures. In addition to JPL General Specification, JPL Procedure and TDM's 0011, 0019, 0022, 0024, 0028 and 0030, the following was done.

Glass capsules were cleaned and bagged in previous operations. For applying strain gages, each capsule is placed in an isopropyl alcohol degreaser for one hour. While the capsules are in the degreaser, the strain gages are prepared. The EPY-150 epoxy is mixed thoroughly and the 4 gages and the terminal evenly coated. The capsule is removed from the degreaser, excess alcohol shaken off and the gages applied while the capsule is still hot. The excess cement and any trapped bubbles are squeezed from under the gages with a teflon paddle and/or Kimwipes. Next, the silicone gum wrapper is placed around the gages, 5-15 PSI pressure applied and two full wraps of Scotch Tape No. 600 applied to hold the assembly together. The final operation is to place the capsule in the air circulating oven to cure at 150^{o}F for one hour, followed by removal of the silicone wrapper. Next, the bridge network is wired using bare No. 34 AWG wire. Bean flux remover is used to clean the soldered joints, as necessary. The bare wire is covered with a thin coat of Gagekote No. 4 water proofing compound to anchor the wire. Capsules are now post cured for 3 hours at 200°F, then 150°F for 17-18 hours.

4.3 Transducer Connections

The inner connections of the four arms of the strain gage bridge wires were laid out as shown in Figure 1 (JPL Drawing 100 30007). The principal technical caution in wiring the bridge wires to the gages and to the pad was to avoid excessive heat. The result of excessive heat could be spotted visually as a void that formed between the epoxy cement and the strain gage. (If this condition occurred, the capsule was rejected.)

All solder joints were made using a 6 watt soldering iron supplied by a Variac controlled power supply. The voltage used in soldering was 90 volts AC.

4.4 Capsule/Transducer Curing Techniques

JPL Procedure EP 504576A, Paragraph 5.1, steps No. 10, 14, and 25 specifies the latest curing techniques developed under the contract. Figure 16 shows the air circulated oven used for curing. During the process of transporting the capsule/transducers to the oven, wooden holding racks and plastic containers are used. The capsule/transducers are laid horizontally in the oven on top of a stainless steel wire shelf, with the strain gages up. Great care was taken to avoid placing any stress on the glass capsules during the curing cycle.

4.5 Capsule/Transducer Pre-Calibration Method

Because of a high capsule/transducer rejection rate early in the program, about 15% during calibration, PSI developed a console to pre-calibrate capsules (Figure 19). This step reduced capsule rejections appreciably. It was accomplished after post curing the strain gages, but before loading the specimen and fusing the reducer to the capsule neck.

Lead wires were soldered to the tie pad and a pre-balance to 120 microvolts was made using the specified JPL procedures. Each individual capsule/transducer was placed in an aluminum pressure fixture (Figure 19). A pressure tight seal was made between a neoprene rubber disc in the fixture against the top of the glass capsule. The strain gage lead wires were connected to a microvolt meter and the bridge excited with 5 volts DC. The capsule was pressurized to 50 psi and the voltage output measured. Through experience it was found that if the sensitivity of the capsule/transducer was at least 6 microvolts/psi, the unit would pass further processing and subsequent calibration with no difficulty of being above the minimum allowable sensitivity. After pre-calibration, all additional basic steps in JPL Procedure EP 504576A were followed.

4.6 Capsule/Transducer Calibration Technique

Final capsule/transducer calibration was made in accordance with the procedures and requirements specified by JPL (JPL Specification FS 505030). A maximum of twenty (20) capsule/transducers could be calibrated simultaneously in the JPL designed test set up (Figure 25). Each capsule/transducer was wired to the Data Acquisition System individually. The reference transducer was monitored continuously and each test capsule, in sequence, was individually monitored, and the readings recorded on print paper. Each capsule/transducer was checked for zero shift, output over a range of pressures from 0 to 64 psia, and output sensitivity in microvolts per psia.

4.7 Fabrication and Preparation of Specimens

Figure 2 presented the flow sequence in the fabrication and preparation of metallic specimens. JPL Process Specification FS 505029 is the principal document delineating specimen procurement requirements, specimen traceability, fabrication, cleaning, passivating, stocking and loading.

The method for controlling the work steps in the PSI plant (and at outside vendors) was to use the existing PSI "Production Planning Schedule" sheets (Figures 34A and 34B). These were prepared by PSI Planning Department and a copy followed each part or lot in the fabrication process.

PSI wrapped each specimen in aluminum foil after it had passed inspection in the Clean Room Trailer, then sealed it in a polyethylene bag with an identification slip. This kept each specimen clean and separate until it was ready to be loaded in the capsule/transducer.

4.8 Specimen Loading Procedure

Prior to loading material compatability specimens into the capsule/transducer, both units were thoroughly cleaned.

The capsule/transducers were partially filled with Freon-TF; this was carefully swirled around the inside surface and poured out. This operation was then repeated with fresh Freon. The capsule was allowed to air dry. Throughout the handling procedure, no chlorinated substances were allowed in contact with the capsules. All the above handling prior to loading was accomplished in the Clean Room Trailer under very carefully controlled cleanliness levels.

Similarly, the specimen was thoroughly cleaned, first degreased by immersion in acetone and air dried. The second cleaning operation (inside the Clean Room Trailer) was to wash with 4.0% solution of liquid detergent, at $180 \pm 30^{\circ}F$ for five minutes minimum. After thorough water rinsing, the pH of the run off water was compared with clean distilled and deionized water.

PSI **PRODUCTION PLANNING SCHEDULE** SERIAL NO 320

Revision Letter N/C SHEET 1 OF 2

PLANNED BY	M. CONRAD	DATE 12/14/67	PART NO. SK 360
APPROVED BY	R. Walls	DATE 2/15/68	DWG. AND CHG. LET. SK 360 SHT. 1 N/C
MAT L SIZE AND TYPE	.062 x .625 x 3.187		DESCRIPTION METAL SLUG
SPECIFICATION	AS APPLICABLE		
NO. PCS. PER STOCK SIZE			
NEXT ASS'Y		NO. REQ'D	FINAL ASS'Y / NO. REQ'D

OPER. NO	INSTRUCTIONS (OPERATIONS)	TOOL NO.	REMARKS
1	DRAW .062 SHEET MATERIAL WHICH IS DESIGNATED ON SHOP TRAVELER. RECORD MATERIAL HEAT OR LOT NUMBER ON SHOP TRAVELER.		
2	CUT TO A BLANK SIZE OF .062 x .625 x 3.187 DE-BURR EDGES. INSPECTION REQUIRED.		
3	MILL THE END DIMENSION OF 3.00 ± .010 PER DRAWING.		
4	MILL WIDTH DIMENSION OF .500 ± .010 PER DRAWING.		
5	DIMENSIONALLY INSPECT FOR COMPLIANCE OF OPERATIONS 3 & 4.		
6	ROUGH GRIND THEN LAP THICKNESS TO .030 ± .001 WITH A-16 OR BETTER FINISH. INSPECTION REQUIRED.		
7	LAP EDGES TO A-16 OR BETTER FINISH.		
8	DIMENSIONALLY INSPECT SPECIMENS FOR COMPLIANCE WITH THE DRAWING. RANDOMLY SELECT ONE SPECIMEN FROM THE LOT AND IDENTIFY IT AS THE LOT TEST SPECIMEN. VIBRA ETCH SERIAL NUMBERS ON EACH SPECIMEN PER THE DRAWING IN ACCORDANCE WITH THE SERIAL NUMBERS ASSIGNED ON THE SHOP TRAVELER. INITIATE AN IN-PROCESS INSPECTION REPORT #131 FOR EACH SPECIMEN. KEEP IN-PROCESS INSPECTION REPORT WITH SPECIMENS UNTIL THEY GO IN THE CLEAN ROOM.		

Figure 34A

PSI PRODUCTION PLANNING SCHEDULE SERIAL NO. 320

Revision Letter N/C SHEET 2 OF 2

OPER. NO.	INSTRUCTIONS/ OPERATIONS	TOOL NO.	REMARKS
8	(CONTINUED)		
	SUBMIT EXTRA SPECIMENS TO PRODUCTION CONTROL.		
9	DEGREASE THE SPECIMENS BY CLEANING WITH ACETONE. NOTE APPROVAL ON IN-PROCESS INSPECTION REPORT #131.		
10	PASSIVATE THE SPECIMENS IN ACCORDANCE WITH THE REQUIREMENTS FOR THE RESPECTIVE ALLOY AS FOUND IN JPL SPECIFICATION GMZ-50521-GEN-I APPENDIX I. NOTE APPROVAL ON IN-PROCESS INSPECTION REPORT. HEAT SEAL SPECIMENS INDIVIDUALLY IN CLEAR PLASTIC BAGS.		
11	STOCK SPECIMENS.		

Figure 34B

Only .5 pH units difference in pH was allowed.

The specimen was dried using dry nitrogen gas filtered through Robbins Filters.

Great care was taken to eliminate any chlorinated materials from coming in contact with either the capsule or the specimen.

Any step or process where the specimen or capsule was touched by human hands was avoided by wearing lint free gloves in all such operations. The rest of the specimen loading procedures followed JPL requirements.

4.9 Propellant Filling Procedure

Propellants were picked up at JPL's Edwards Test Station by PSI truck in a frozen state. Only one propellant was handled at a time at PSI and only in quantities of one liter or less. In most all cases, the propellant was picked up one day, the capsule-transducers filled the following day and the capsule shipment returned to ETS either the afternoon of the second day or the morning of the third day.

The actual propellant filling and handling procedures are shown in Figures 27, 28, 29 and 30. JPL Specification FS 505029 gives the propellant filling steps and sequence.

Safety precautions observed in handling propellants are discussed in Paragraph 4.12 below.

4.10 Specimen/Capsule Hermetic Sealing Procedure

The final Clean Room Trailer operation conducted by PSI was to seal the capsule/transducer. First, the unit was evacuated (with the propellant frozen) and the capsule vacuum maintained with a pinch cock sealing a rubber tube over the glass reducer end. This operation was conducted under the explosion proof fume hood. (See Figure 31)

Next, the frozen capsule with the rubber tubing and pinch cock secured to the reducer end is moved above the torch. The section of the glass reducer with the constriction is placed in the oxy-propane torch flame, and the glass, when soft, sealed and separated to make a hermetic seal. (Figures 32 and 33).

4.11 Shipping Methods

PSI shipped all capsules to JPL on standard PSI three part shippers. Each capsule/transducer test number was listed individually. Because filled capsules were not permitted to remain at PSI for any unnecessary length of time, shipments were made as soon as possible after the last capsule was sealed. The PSI truck and driver made all deliveries. Subsequently, the entire data package for the shipment was delivered to JPL.

4.12 Safety Precautions

During this program, several meetings with the cognizant JPL Safety Engineer, with JPL professionals and with the Los Angeles Fire Department were held to insure that all pertinent safety precautions in handling propellants were observed. PSI originated four safety procedures and instituted personnel safety training in handling propellants and emergency procedures in case of fire.

The following PSI documents involved propellant safety precautions:

1) PSI Procedure No. 65-000001, "Emergency Procedures for Hydrazine Handling"
2) PSI Procedure No. 65-000002, "PSI Safety and Handling Procedure for Loading Capsules with Hydrazine (N_2H_4) Propellant"
3) PSI Procedure No. 65-000003, "Handling and Emergency Procedures, Nitrogen Tetroxide (N_2O_4) Capsules"
4) PSI Procedure No. 65-000014, "Handling and Emergency Procedures, Monomethylhydrazine (CH_3NHNH_3) Capsules."

In addition to briefing all personnel directly involved in propellant filling operations, a third safety man was trained. This person would be outside the Clean Room Trailer and was available in case of emergency. The third man was trained in using a Scott Air Pack No. 2 Emergency Oxygen System with which to rescue unconscious personnel from the trailer in case of fire or an accident.

Finally two fire extinguishers and an emergency eye wash system were available inside the trailer, an emergency exit from the trailer opened on a platform with an emergency "one pull" shower.

4.13 Clean Room Trailer and Cleanliness Criteria

The PSI Clean Room Trailer was designed to and meets Federal Standard 109 class 100 cleanliness requirements. The trailer was tested by a certified vendor, Dust Control, Inc. The PSI Clean Room Trailer was certified to class 100 and has maintained its certification at all times. This class exceeds all requirements of JPL Specification No. 15013 called out in the contract.

The PSI Technician (Appendix II) used for all cleaning operations on this program came to PSI from a vendor who specializes in U. S. Government Contract Clean Room Operations. He has been on the JPL contract continuously and is meticulous in his performance of cleanliness requirements and recording required data.

4.14 Miscellaneous Equipment

Various specialized pieces of equipment were designed and built or purchased for this contract to facilitate work efficiency. The principal items are discussed below.

Two alcohol vapor degreasers for cleaning capsules prior to laying strain gates were fabricated by PSI for this program. The first unit held 8 capsules, the second 14 capsules. The units were used simultaneously to increase production.

A stainless steel basket for annealing glass capsules was fabricated. The basket could hold up to 500 capsules.

A teflon holding rack was fabricated for use inside the Clean Room Trailer. This three tier rack was superior to the two tier wooden racks used outside of the Clean Room Trailer.

5.0 DOCUMENTATION PERTINENT TO SPECIMEN – CAPSULE/TRANSDUCER PREPARATION

Specimen "In-Process Inspection Report" Form No. 131 was used to record specimen characteristics, production sequences and accompanied each material compatability test specimen. Each specimen was assigned a four digit test number. Figures 35A and 35B are representative sample sheets filled out for a specific test specimen.

In addition a "Test Data Sheet" – Form 132 (Figure 36) accompanied each test specimen. The Test Data Sheet was used to record physical data on the specimen recorded after processing sequences were completed. This form was filled out and completed in the Clean Room Trailer (refer to Figure 22 for cross reference).

Capsule/transducer calibration data, obtained as a voltage output from the strain gages versus pressure inside the capsule, was recorded automatically by the Data Acquisition Systems. Representative data is presented in Figures 37A, 37B and 37C. Figures 25 and 26 show the Data Acquisition System.

Form No. 131
Sheet 1 of 1

IN-PROCESS INSPECTION REPORT

Test Number: 1911

Dash Number: "A"

Material Designation: 6061 T6 AL

Material Log Number: LOT NO. 1

Sample Type: BI-METAL (SK363)

Passivating Procedure: GMZ 50521 A

Joining Process: ____________

INSPECTIONS & CERTIFICATIONS

	Inspection Stamp
A. Dimensions	
1. Length	PSI 4
2. Width	PSI 4
3. Thickness	PSI 4
4. Contour	PSI 4
B. Surface Roughness	
1. Faces	PSI 4
2. Edges	PSI 4
C. Identification	PSI 4
D. Joining	
E. Passivating	PSI 4
F. Cleaning	PSI 4
G. Packaging	PSI 4

Date: DEC. 16, 1969

Inspected By: PSI 4

Figure 35A

Form No. 131
Sheet 1 of 1

IN-PROCESS INSPECTION REPORT

Test Number: 1911 Dash Number: "B"

Material Designation: 347 SS

Material Log Number: 3342117

Sample Type: Bi-Metal (SK362)

Passivating Procedure: GMZ 50521 A

Joining Process: ______

INSPECTIONS & CERTIFICATIONS

	Inspection Stamp
A. Dimensions	
1. Length	PSI 4
2. Width	PSI 4
3. Thickness	PSI 4
4. Contour	PSI 4
B. Surface Roughness	
1. Faces	PSI 4
2. Edges	PSI 4
C. Identification	PSI 4
D. Joining	
E. Passivating	PSI 4
F. Cleaning	PSI 4
G. Packaging	PSI 4

Date: Dec. 16, 1969 Inspected By: PSI 4

Figure 35B

TEST DATA SHEET

Test Number: 1911

Sample Type: BI-METAL CONTACT

Test Cell Location No.: ____________

Material Designation: A 6061 T6 AL

B 347 SS

Material Log No.: A LOT NO. 1

B 3342117

Capsule No.: 724 Calibration Date: DEC. 22, 1969

Capsule Loading Date: DEC. 23, 1969

Propellant Analysis No.: ____________

Cleaning Inspection Signature M.J.K. PSI

DATA

1. MEASUREMENTS	INITIAL	FINAL	% CHANGE
Sample Weight, gm, A	0.9155		
Sample Weight, gm, B	2.7552		
Sample Thickness, in, A	.0291		
Sample Thickness, in, B	.0304		
Sample Length, in, A	2.9653		
Sample Length, in, B	2.9915		
Sample Width, in, A	.2360		
Sample Width, in, B	.2363		
* Shore Hardness 1			
2			
3			

* Not applicable for metallic specimens

Figure 36

CAPSULE CALIBRATION DATA

JPL CONTRACT NO. 952004

CALIBRATION TEST NO. 024

PSI JOB NO. 6720

DATE: DEC. 22, 1969

CAPSULE SERIAL NO. 719 THRU 738

TIME: 9:00 A.M. THRU 2:00 P.M.

CH. NO.	CAP S/N	CHG. NO.	CAP S/N	CH. NO.	CAP S/N	CH. NO.	CAP S/N
1	719	6	724	11	729	16	734
2	720	7	725	12	730	17	735
3	721	8	726	=3	731	18	736
4	722	9	727	14	732	19	737
5	723	10	728	15	733	20	738

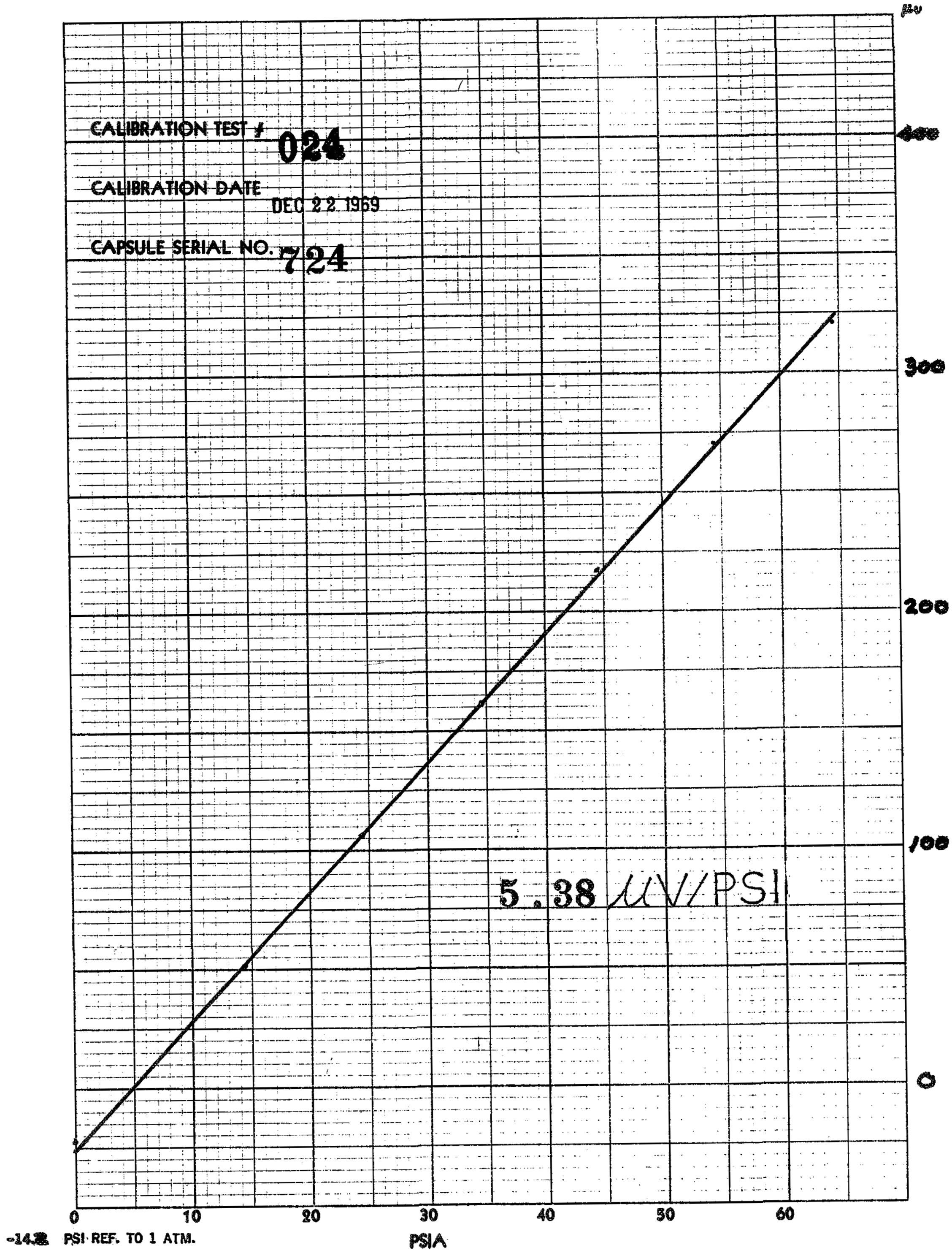
CHANNEL DESCRIPTION

CHANNELS 1 THRU 20----------------CAPSULE OUTPUT DATA IN MICROVOLTS
CHANNEL 21------------------------PRESSURE IN PSIG (000.0 PSIG)
CHANNEL 22------------------------CAPSULE TEMPERATURE IN MILLIVOLTS
109°F. = 1.72 MV, 109.5° F. = 1.73 MV
110° F. = 1.74 MV, 110.5° F. = 1.755 MV
111° F. = 1.77 MV
CHANNEL 23------------------------EXCITATION VOLTAGE IN VOLTS D.C. (5.000)
CHANNEL 24------------------------SHORTED INPUT IN MICROVOLTS
CHANNEL 25------------------------RUBICON STANDARD SET AT 1.000 MILLIVOLT

REMARKS: ALL CAPSULES PROCESSED PER JPL's TDM 0054

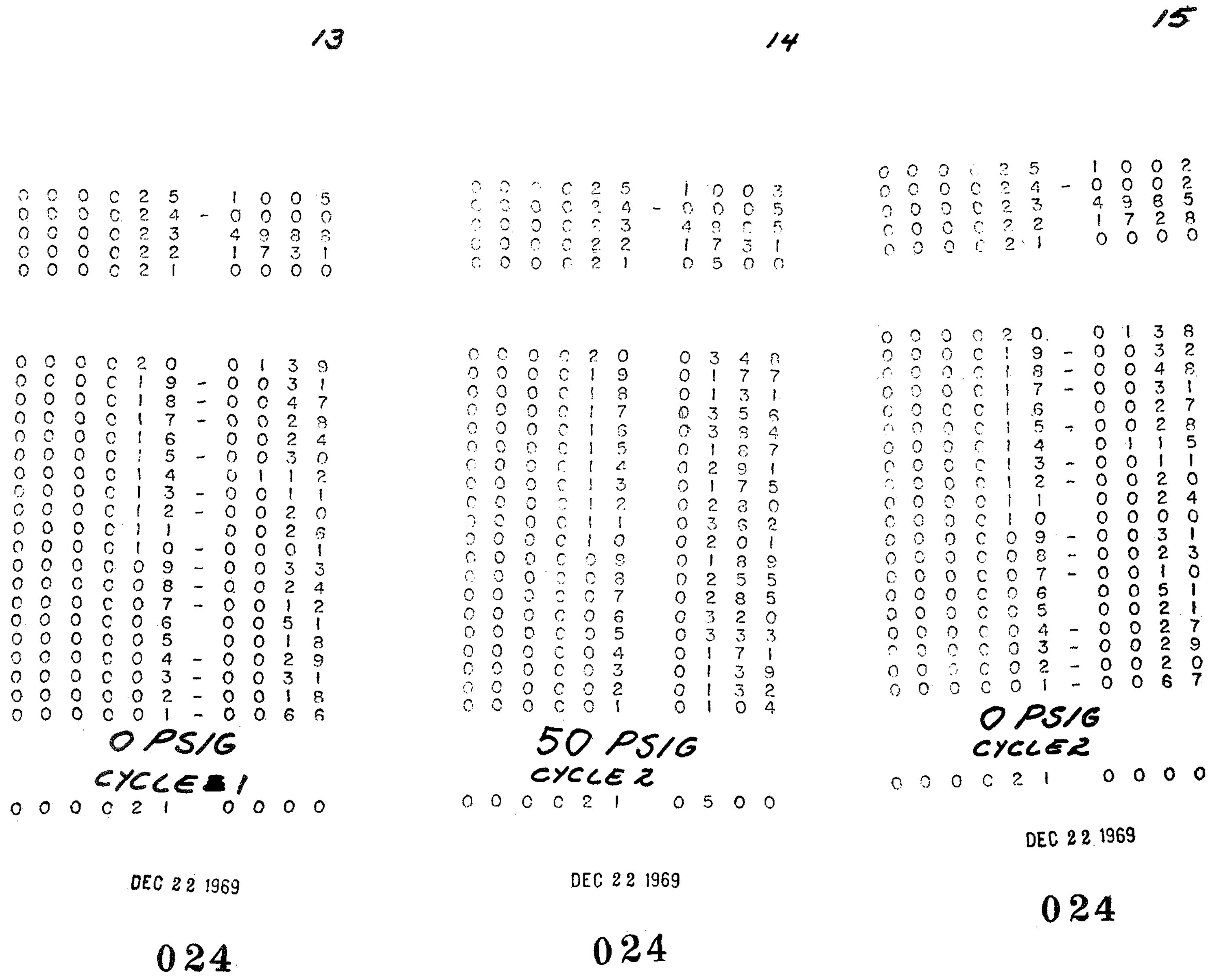
CAPSULES PASSED 20
CAPSULES FAILED 0

Figure 37A



CALIBRATION TEST # 024
CALIBRATION DATE DEC 22 1969
CAPSULE SERIAL NO. 724
5.38 μV/PSI
μv
400
300
200
100
0
0
10
20
30
40
50
60
-14.2 PSI REF. TO 1 ATM.
PSIA

Figure 37B



TYPICAL OUTPUT FROM THE DATA ACQUISITION SYSTEM

Figure 37C

6.0 ANALYSIS OF RESULTS

6.1 Discussion of Problem Areas

During the period the Long Term Compatability Program was underway at PSI several problem areas developed which were primarily attributable to changing from a very low volume production rate in a highly technical laboratory to a relatively high production rate in a commercial plant. The following discussion analyzes the principal problems encountered.

Method of Cutting Test Specimens: Several methods of cutting test specimens in quantity were tried:

1) Wet Abrasive Sawing,
2) Shearing, and
3) Band Saw Cutting with Water Mist Cooling.

The basic problem was to eliminate residual thermal stresses in the samples edges and/or distortion and residual stress of specimen edges by mechanical shearing. After several tests, band saw cutting by hand with water mist cooling of individual specimens was specified by JPL.

Glass capsule annealing: The annealing cycle and proof of temperature profile used by the glass test tube manufacturer was not considered satisfactory by JPL. Consequently, an investigation was made by JPL to develop an acceptable glass annealing procedure which would eliminate residual stresses. Concurrently, PSI determined through a detailed temperature survey exactly what degree of control could be obtained from the PSI Heat Treat Furnace Controllers and also the temperature distribution profile throughout the interior of the furnace. Based on this data a limited quantity of capsules were annealed by PSI. JPL then analyzed the capsules for residual stresses and quality of the annealing cycle. As discussed in Paragraph 4.1, the final procedure was specified by JPL TDM's.

Strain gage assembly procedure: Considerable thought was given to the strain gage positions on the glass capsules. Constraints were the location of the clips on the specimen/capsule test fixture at JPL/ETS, the zone of residual thermal stresses from glass fusing and provision for adequate working space for the technician to be able to "lay" the gages. Preparation of the capsule surface prior to bonding to eliminate surface contamination was another important requirement. JPL representatives briefed PSI personnel on all facets of producing satisfactory capsule/transducers and actually made the first few capsule/transducers at PSI. PSI proposed and built a mechanical clamp to hold the four strain gages while initially curing. However, this fixture was shown to be less desirable than using the silicone gum wrapper and was abandoned. Another problem area was the curing cycle of the bonding cement. This was resolved by TDM's 0028, 0045 and 0054.

Water proofing procedure: JPL Specifications initially called for using GW-1 Silicone Resin Waterproofing Compound as a final coating over the strain gages (in case all capsules were washed with water because one capsule burst and spilled propellant). Considerable testing demonstrated that Gagekote No. 4 was superior and was subsequently specified by TDM No. 0030. In addition the Gagekote No. 4 curing cycle required verification to ensure repeatable strain gage performance after curing.

Specimen Distortion: Some metallic specimens were required to be heat treated in an inert atmosphere (argon). The first few batches warped out of print dimensions during heat treat. The solution was to straighten the specimens during ageing back to print dimensions.

Balance —Drift: Glass capsule/transducers are required to measure very small strains and give very low (microvolt) outputs as stresses. These stresses were calibrated as pressure changes in the initial calibration procedures. However, capsules were proven to have some balance drift as a result of the capsule thermal history in curing the cement and water proofing compound.

Glass Capsule Imperfections: The "Balance – Drift" problem resulted in a thorough analysis of the quality of the glass capsules. This included tests to determine the variation in glass capsule thickness from capsule to capsule, as well as around the diameter of any given capsule. A thorough investigation of these areas was made by JPL and results provided PSI in the TDM's discussed previously.

Broken Capsules: Several capsules were broken due to the shape of the bottoms of the glass sample separators. TDM 0044 allowed PSI to flatten the bottoms of the separators slightly which solved the problem.

Freezing of N_2O_4 Propellant: The freezing procedures using an alcohol - dry ice slurry to freeze hydrazine (N_2H_4) was not successful with nitrogen tetroxide (N_2O_4). This slurry was replaced with liquid nitrogen (LN_2) which very definitely froze the propellant. However, the Gagekote water proofing compound over the strain gages cracked, producing hairline cracks at random. This cracking was obviously undesirable. After several experiments, a procedure was developed involving a flash freeze of the propellant, exposing only the bottom of the capsule, followed by maintenance of the frozen state in powdered dry ice.

Data Acquisition System: Occasionally the Data Acquisition System malfunctioned and required JPL maintenance and/or repair. Most frequently this occurred on start up of the system to calibrate capsule/transducers, necessitating a delay in the procedure with that specific batch of capsule/transducers.

6.2 Impact of Industrial Practices

On several occasions the normal commercial practice, which would have been the high volume production method, was not used because of incompatibility with the overall program objectives. A clear example was the method of cutting the many metallic specimens. If shearing had been allowed, the entire batch of compatibility materials could have been cut to size rapidly. But shearing would probably have distorted the edges and possibly left unknown residual stresses in the specimens. Consequently, shearing was rejected and band saw cutting was used with continuous water mist cooling to avoid thermal stresses.

Another unique program requirement that necessitated special handling was the preparation of relatively small batches of different metallic specimens, instead of long runs of essentially identical parts, the normal industry requirement. Concurrently, the program requirement of a new and clean set up for each batch resulted in higher costs. A specific charge was made by the vendor for cleaning equipment between each run plus a set up charge for each configuration. In double disc grinding operations, the program requirement for a new set of wheels for each batch of specimens was modified to dressing both wheels between each separate specimen run.

Finally, the specimen preparation was unique enough that the double disc grinding vendor (Cal-Disc) had to run a small development investigation. Two batches of specimens were lost before the techniques were refined to produce acceptable specimens.

Prior to full scale production, JPL was furnished test specimens which were tested for metallurgical properties. After several process modifications through TDM's (Appendix III), the methods were approved for production.

6.3 Conclusions

The conclusions are:

1) Quantity production of compatibility test capsule/transducers can be achieved.
2) Compatibility test specimens, both metallic and non-metallic, were fabricated in volume to meet program requirements.
3) A grand total of 872 compatibility capsule/transducers, control capsules, and test capsules were delivered to JPL under this contract through March 1970.
4) A significant number of capsule/transducers and specimens remain as work-in-process under this contract for delivery to JPL.
5) In the opinion of the contractor, continual guidance and supervision by JPL is necessary in order to provide the flexibility to modify and change broad fabrication specifications to meet recurring detailed program requirements in a practical manner.
6) Fabricating specimens in excess quantity is easier than losing one entire group and being forced to start from the beginning in the fabrication cycle.

6.4 Recommendations

The recommendations are:

1) The identification/numbering system be simplified in so far as possible.
2) A lot or batch system be provided to enable easier processing.
3) The feasibility of procuring a complete strain gage/terminal strip network in one unit from the strain gage manufacturer be investigated.
4) A factor of at least three spare specimens be provided for each compatibility specimen required.

APPENDIX I

SHIPPER NO.	SHIPPING DATE	SHIPPED TO	ITEMS SHIPPED
1777	7/30/68	JPL - ETS	17 Hydrazine Capsules
1788	8/30/68	JPL - ETS	20 Hydrazine Capsules
1805	10/25/68	JPL - ETS	33 Hydrazine Capsules
1815	11/14/68	JPL - ETS	36 Hydrazine Capsules
1819	12/5/68	JPL - ETS	12 N_2H_4 Control Capsules
1819	12/5/68	JPL - ETS	2 Special Test Capsules
1832	1/3/69	JPL - ETS	12 N_2H_4 Control Capsules
1847	2/7/69	JPL - ETS	4 Hydrazine Control Capsules
1850	2/14/69	JPL - ETS	31 Hydrazine Capsules
1875	4/4/69	JPL - ETS	30 MMH Capsules
1879	4/9/69	JPL - Pasadena	10 Capsules
1883	4/18/69	JPL - ETS	4 MMH Control Capsules
1884	4/18/69	JPL - ETS	31 MMH Capsules
1884	4/18/69	JPL - ETS	4 Control Capsules
1893	5/6/69	JPL - ETS	33 Open End Control Capsules TDM 51
1896	5/8/69	JPL - ETS	26 N_2O_4 Capsules
1896	5/8/69	JPL - ETS	3 Control Capsules
1897	5/20/69	JPL - ETS	3 N_2O_4 Control Capsules
1898	5/23/69	JPL - ETS	25 N_2O_4 Capsules
1898	5/23/69	JPL - ETS	1 Control Capsule
1905	6/10/69	JPL - ETS	40 MMH Capsules
1905	6/10/69	JPL - ETS	4 Control Capsules
1908	6/26/69	JPL - ETS	31 Hydrazine Capsules
1908	6/26/69	JPL - ETS	4 Control Capsules
1925	8/6/69	JPL - ETS	30 Hydrazine Capsules
1925	8/6/69	JPL - ETS	4 Control Capsules
1928	8/20/69	JPL - ETS	24 N_2O_4 Capsules
1928	8/20/69	JPL - ETS	4 Control Capsules
1938	9/5/69	JPL - Pasadena	10 Capsules - Table IV

APPENDIX I
(Continued)

SHIPPER NO.	SHIPPING DATE	SHIPPED TO	ITEMS SHIPPED
1941	9/25/69	JPL - ETS	33 N_2O_4 Capsules
1941	9/25/69	JPL - ETS	4 Control Capsules
1952	10/22/69	JPL - Pasadena	36 Capsules - Table IV
1952	10/22/69	JPL - Pasadena	4 Control Capsules
1961	11/6/69	JPL - Pasadena	34 Capsules - Table IV
1961	11/6/69	JPL - Pasadena	4 Control Capsules
1973	11/20/69	JPL - ETS	36 N_2O_4 Capsules
1973	11/20/69	JPL - ETS	4 Control Capsules
1973	11/20/69	JPL - ETS	24 Capsules
1973	11/20/69	JPL - ETS	1 Test Capsule
1986	12/30/69	JPL - Pasadena	23 Capsules - Table IV
1986	12/30/69	JPL - Pasadena	4 Control Capsules
1987	12/31/69	JPL - Pasadena	30 Capsule/Transducers
1998	1/21/70	JPL - ETS	36 N_2O_4 Capsules
1998	1/21/70	JPL - ETS	4 Control Capsules
2134	3/31/70	JPL - Pasadena	107 Glass Capsule/Transducers
		Total Items Delivered	872

APPENDIX II

PSI TECHNICIANS USED ON THE JPL COMPATIBILITY PROGRAM

Hazel M. Mathews

Electronic Assembler
Certified to PSI Specification 65-000008

Dale E. Pollock

Inspector, Electronic
Certified to PSI Specification 65-000008

Michael J. Kosareff

Clean Room Technician
Certified by PSI Quality Assurance Department

APPENDIX III

TECHNICAL DIRECTION MEMORANDUMS

ISSUED BY JPL ON CONTRACT NO. 952004

NUMBER	DATE	SUBJECT
0001	1/11/68	Numbering System
0002	1/15/68	Spectrographic & Hardness
0003	1/15/68	Titanium Ageing
0004	1/15/68	Bi-Metallic Standards
0005	1/15/68	Glass Capsule Identification
0006	1/15/68	Bi-Metal Data
0007	1/19/68	Tolerances
0008	1/19/68	.010 From Surface
0009	1/19/68	Weld-Butt
0010	1/25/68	Handling (Plugs)
0011	1/26/68	Strain Gages
0012	2/7/68	Double Disc-Slurry
0013	2/7/68	Saw Cut
0014	2/18/68	6.5.1 Handling Container
0015	3/21/68	Glass Anneal Cooling Rate
0016	3/21/68	Capsule Annealing, 250 500 etc.
0017	3/22/68	304 S. S. - 304 LS
0018	3/22/68	3.00 & .010 Stressed Sample
0019	3/22/68	Sand Erase - Gage Location
0020	3/22/68	Certified Clean Room
0021	3/22/68	Metallic Samples
0022	4/2/68	AWG 34 Wire
0023	4/16/68	Cleaning, Etc.
0024	4/23/68	Strain Gage Voltage
0025	5/3/68	Hydrazine Analysis
0026	5/17/68	Teflon Vice Nylon Wire
0027	5/24/68	Operational Check Lists
0028	6/28/68	Strain Gage Installation
0029	6/28/68	Test Capsule Sample Loading

APPENDIX III

(Continued)

NUMBER	DATE	SUBJECT
0030	6/28/68	S. G. Waterproofing
0031	7/1/68	Balance Range For 1st 25 Capsules
0032	7/31/68	Stressed Sample
0033	7/31/68	Capsule Filling
0034	7/31/68	Identification
0035	8/1/68	Sample Loading
0036	8/6/68	MMH Propellant
0037		
0038		
0039	10/4/68	Calib. in Abs. Pressure
0040	9/30/68	Time at Temperature, Change
0041	9/30/68	Annealing of Test Capsules
0042	10/4/68	N_2H_4 Analysis
0043	10/4/68	Capsules No. 1 - No. 77
0044	10/17/68	Flattening Glass Sample Separators
0045	11/4/68	Gage-Cement Curing Operation
0046	11/7/68	Number of Control Capsules
0047	1/9/69	Calibration Control, Test - Capsules (4)
0048	2/3/69	Thickness Requirements
0049	3/18/69	Order of Processing (MMH) Test Samples
0050	4/7/69	Modification, Welded and Stressed Specimens
0051	4/18/69	Calibration Control, Test - Capsules (40)
0052	4/22/69	Handling & Emergency Procedures, Nitrogen Tetroxide Capsules
0053	8/5/69	Delivery Schedule
0054	8/8/69	Air Cooled Furnace
0055	10/16/69	PE Protective Wrapper
0056	11/19/69	Annealing Instruction for Remaining Capsules
0057	12/1/69	Specimen/Capsule Low-Sensitivity Rejects
0058	12/11/69	Request - Technical Support
0059	3/25/70	Delivery, Remaining Capsules